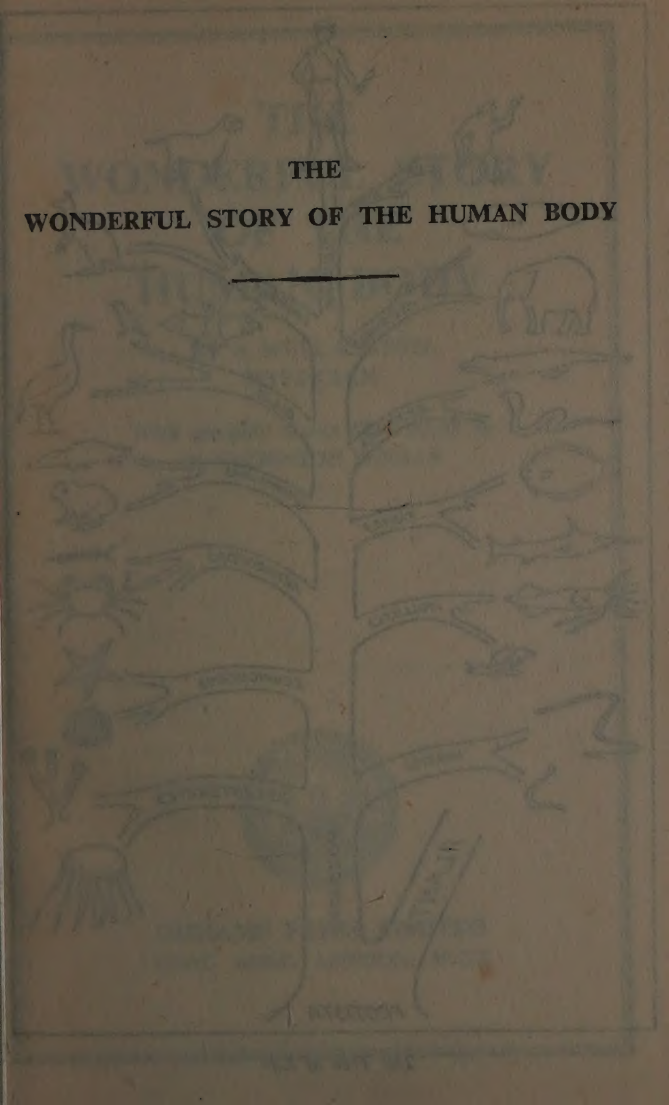
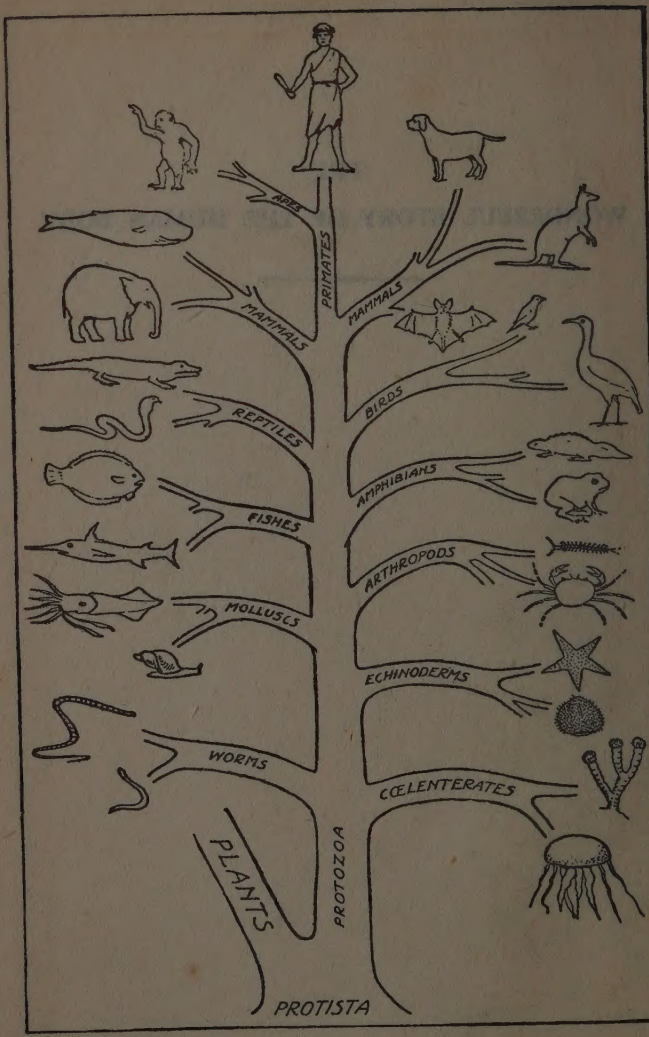
THE
WONDERFUL STORY OF THE HUMAN BODY





The Tree of Life

THE WONDERFUL STORY OF THE HUMAN BODY

BY A WELL-KNOWN PHYSICIAN

With specially drawn illustrations by
W. THORNTON SHIELLS

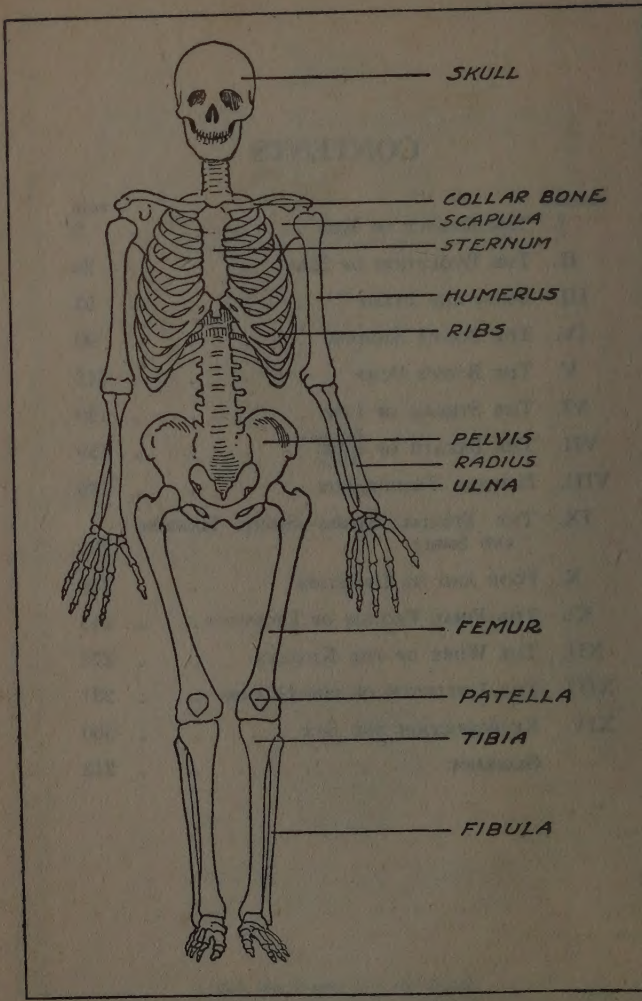
ODHAMS PRESS LIMITED
LONG ACRE, LONDON, W.C.2

Copyright
G.638

Made and Printed in Great Britain
by Odhams (Watford) Ltd., Watford

CONTENTS

CHAPTER		PAGE
I.	The Essence of Life	9
II.	The Evolution of Man	28
III.	Bones and Flesh	53
IV.	The Body's Armour	93
V.	The Body's Pump	112
VI.	The Stream of Life	139
VII.	The Breath of Life	159
VIII.	Nervous Telegraphy	180
IX.	The Special Senses—Sight, Hearing and Smell	204
X.	Food and its Digestion	229
XI.	The Final Process of Digestion	253
XII.	The Work of the Kidneys	272
XIII.	The Influence of the Glands	287
XIV.	Reproduction and Sex	300
	Glossary	312



The principal bones of the human body

INTRODUCTION

THE Story of the Human Body is not merely wonderful—it is unique. Most stories have a beginning and an end. That of the human body is cut short abruptly in the full flow of its course. Where will it end?

In this book an endeavour has been made to sketch in the broadest manner the struggles of life which have culminated in the structure which we call the human body. This struggle has followed certain rules known as the Laws of Evolution. These laws have helped to mould and shape the crowning masterpiece—*Homo sapiens;* and man's body contains signs of this struggle of the past—the vestigial organs.

In describing the body, emphasis has been laid on the function or working of the organs, far more than on details of structure. There is much detail, however, in the delightful drawings of Mr. Thornton Shiells which would have taken pages of description, and would even then have been very much more difficult to understand. All these drawings have been discussed very carefully and designed to illustrate and amplify the points in the text. I would like to take this opportunity of acknowledging Mr. Thornton Shiells's most pleasant co-operation.

The book has been systematically built up from the beginning, with the result that it is not a book to be "dipped into" at random. Simplicity has been aimed at in every sentence. But the human body can hardly be termed a simple problem even by the most optimistic, and at times difficulties may be encountered and, it is hoped, surmounted. Almost everything worth understanding requires some effort, and the body is no exception.

Both our knowledge and our ignorance of the various fundamental processes of the body are worth noting. Very often the dim borderland where knowledge ceases and ignorance begins, is shrouded in a fog of high-sounding theories and hypotheses. These latter have been reduced to a minimum, in the hope that the problems facing those who are penetrating the darkness of ignorance, shall be clearer to the reader. The writer feels that if only the so-called "ordinary person" understands a little what

research is "getting at," he will give it more enthusiastic support—the lack of which is only too noticeable in this country of ours.

Particular emphasis is laid on the importance of considering the body as a whole. Unfortunately, psychology has been unable to find a place, for various reasons, the most cogent of which is that this science is so young that it is almost impossible to separate fact from fiction. This does not mean that it is not important.

In an age where everything is analysed—or taken to pieces—it is of vital importance to realize that it is the building as a whole, and not the bricks of it, which forms the wonderful human body.

This book has but one object—to stimulate a healthy interest in the body. If its readers close it with added understanding and respect for their own familiar bodies, then it has achieved its purpose.

THE AUTHOR.

CHAPTER I

THE ESSENCE OF LIFE

WHAT IS LIFE? This simple question produces the most surprising reactions in philosophers, priests and scientists. For however learned they may be they can none of them supply a simple answer. Theories abound—but facts are tantalizingly few.

Nevertheless although the key of life evades us, we do know most fascinating things about it, and in this first chapter it is these properties of life that we are going to describe. For it is a very remarkable fact that whether in the human body or in the lowliest of creatures, " living " is fundamentally the same process.

THE CHARACTERISTICS OF LIVING THINGS

What are the characteristics essential to living, as opposed to dead, or inanimate things? What is the difference between a complex and beautiful crystal and an *amœba* (pron.: a-meeba) for instance.

First, there is the capacity to move. This may seem strange, at first sight. So many things move, from the moon to dust, and they are not alive. Yes, but the moon moves, only as a result of forces derived from the sun, earth, and other stars and planets. The dust rises in the air only if moved by the wind. Even our beautiful crystal will move only when forced to do so. All these things obey the great law, stated by Newton, that objects remain where they are unless acted on from outside by some force. Not so the amœba ! At its own will—such as it is—it can choose a direction in which to move, and go towards something pleasant, and away from what it finds objectionable. The essential impulse to move comes from within, not without, although, of course, the conditions outside influence it very considerably. And so it is that movement is one of the main expressions of life.

The other almost miraculous property of living things is their power to absorb selected portions of their surroundings and turn them into parts of their own body. This is the capacity to assimilate food. Has it ever occurred to you how remarkable it is that a lump of sugar is broken down, absorbed and stored in your body as fuel in a muscle, and that the same fate overtakes considerable quantities of iron, if presented in the right form. From the delicacy of nectar to the hard rock of salt—the body assimilates them all; builds them all into itself. Not only is it building up flesh in this way, but, in the process, living flesh is broken down again and thrown out of the body. This whole process is known as metabolism. Breathing is a special kind of *metabolism* in which oxygen is used

for burning the fuel in the cells, so that it can perform its function whether it be contraction in a muscle or secretion from a gland, oxygen is always the vital key necessary to the whole process.

And finally there is the capacity of living things to reproduce their kind. As far as we know there is no *new* life being created on this world of ours at present. Nor has there been for many centuries past. All life comes from previous living forms, whether we are discussing *bacteria* or humans. And this reproduction of things in their own image inanimate objects cannot perform.

These three properties then, movement, metabolism and reproduction are life's distinctive signature on the objects around us.

But if there is no new life now, when was there any? When did life first appear on this planet of ours, and under what conditions? These are questions of the first importance to us. For in their answer there might lie the secret of creating life—but we do not know the answer. We can only guess—though that quite shrewdly.

FORMATION OF THE LIVING CELL

Cast into the firmament like a grain of sand in the desert is the sun. Around this larger grain revolve several smaller grains, the planets, of which one is our earth. What utter insignificance! After millions of years of cooling, after the moon has been whirled off into space, there appears on the steaming surface of this revolving globe a layer of rocks—tumultuous, heaving rocks often lit by the glow of fiery volcanoes and molten lava. In the broad arms of time this lurid glow dies down—earth, air, and water separate themselves out from each other. Amongst the elements of this crust is carbon. There are many others, but the carbon atom with its minute "solar system" of six electrons revolving round the central nucleus, is the one that will form the key to the creation of life. As the earth cools, atoms and molecules are formed which combine in indescribable variety and confusion. Some strange combinations containing carbon, hydrogen, oxygen and nitrogen, possess new and strange properties. They adhere together forming a new entity, they form a new "whole" with properties more complex than the most beautiful of jewels. They form life—the living cell.

What is there in the carbon atom that should elevate it to this great distinction? We do not know. We only know that carbon has six electrons—somehow responsible for life, in perhaps a similar way to twenty-six electrons being present where there is magnetism, and eighty to ninety electrons where there is radio-activity.

Is life just an accident of grouping of electrons? Or is it designed? Is there some force that created life out of non-life? Some force which we can recognize as evolution. Is it true to say that this

applies to the simple elements; governing their combination into water (H_2O), acids and salts, etc.; into even higher crystalline beauties; until ultimately by some strange twist, life emerges from the inanimate in much the same way as consciousness and mind will emerge from simple life later on?

THE SIMPLEST FORM OF LIFE

And in what form does new-fledged life emerge? Of recent years forms of life simpler even than the single cell have been discovered—too small to be seen under the microscope—forms which cross that narrow bridge separating chemical *enzymes* (pron.: en-zimes) or ferments from known and living viruses. It was suggested a year or so ago that certain diseases of plants, such as mosaic disease, are due to protein molecules indistinguishable from the smallest viruses. In fact some viruses are said to be merely *protein* molecules—and yet the term "virus" is given to things that appear to be able to reproduce—and so are apparently alive. We know also that the largest protein molecule would only be just too small to be seen by our ultra-microscopes. So that it seems as if we are getting glimpses of the bridge from inanimate to animate—from chemical action to living action!

Man has used ferments from the time of Noah—or at least since about 3500 B.C.—for all wine making utilizes fermentation. But the most studied ferment has been that of yeast. Yeast is a unicellular plant which possesses the capacity of splitting up sugars into alcohol, and is therefore used by the brewer and the baker. One of Pasteur's most famous pieces of work was the discovery of yeast in the brewer's vats, and he insisted that the fermentation depended on the living yeast cell. But Buchner found that an extract (which was active) could be made with no yeast cells in it—this was the first ferment to be isolated. But many others exist and are of great importance in our everyday life—not only in making wines, bread, vinegar, etc., but as accelerators in digestion, breaking down complex chemical molecules into simpler ones.

FERMENTS AND THEIR FUNCTION

The actual structure of these ferments has never been discovered. They are known, and named, by their action. It has been suggested that a ferment consists of two essential parts—a protein in a particular state known as *colloid* (like liquid gelatin), which serves as a carrier of some other substance essential for the fermentation. Ferments are always quite "specific" in their action. For example, the yeast ferment will act only on sugar and break it down into alcohol—it will not act on any other substances such as protein. They all work best at certain temperatures—and this temperature is often that of the human body. Is this a hint of their being alive?

Ferments act like chemical *catalysts* in many ways—and the essence of their action is that they accelerate enormously a reaction which would go on without them, but very slowly. Only a very little ferment is necessary to set the reaction going, a teaspoonful of rennet will act on four hundred thousand times its weight of milk —turning it into curds. And finally we have seen that it is ferments

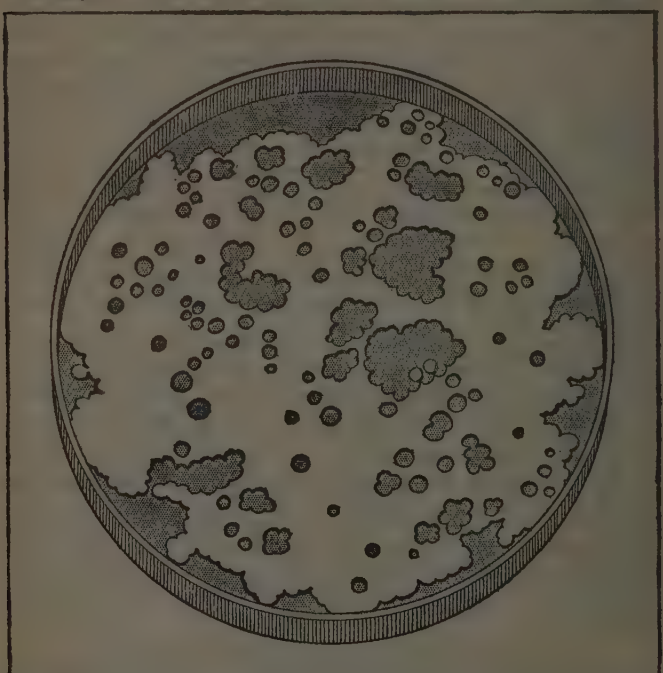


Fig. 1. *A culture plate of dysentery germs being attacked by bacteria destroyers. The round holes show where bacteria have been dissolved.*

or enzymes acting on plants and possibly human tissues, that are responsible for diseases.

One mysterious substance "*bacteriophage*" (pron.: bak-teer-yo-farj) may be a ferment, a *virus*, or both. Its name, given it by D'Herelle in 1918, means "bacterium eater." It is apparently living, and when added to a culture of dysentery *bacilli*

destroys them. The colonies on the plate, as you see in Fig. 1, are dissolved and disappear. Most remarkable of all, D'Herelle found this substance in the stools of patients convalescent from dysentery. It was at once thought that bacteriophage could be applied to medicine—particularly in dysentery, but for some unknown reason it has been a great disappointment. But whether it is an enzyme or a virus that attacks bacteria—a disease of bacteria themselves—it is a very significant phenomenon, and there is no doubt that much is going to be heard of bacteriophage in the future.

From this borderland of dim life, at which we have been glancing, emerges the cell. The basis of cell-structure is *protoplasm*, and we must examine in a little more detail this foundation of living things.

Every one has seen the "white" of an egg before it has been boiled—a slimy, viscous substance, peculiarly unpleasant. When boiled there is formed the firm white material we push our egg-spoons into. Now this slimy material contains myriads of protein molecules in a kind of suspension; when these are heated their electric charges are altered and they group together, changing their state from liquid into solid. This is a property of a group of substances known as colloids. In the liquid form, a colloid is said to be in the "*sol*" state; in the solid, a "*gel*." Protoplasm is a colloid in a "sol" state—a fluid in which ultra-microscopic *granules* are suspended.

WHAT IS PROTOPLASM?

All living things are composed of protoplasm. If looked at under the microscope, this fluid will be found to have granules suspended in it. These are food particles, either in the process of being absorbed, or excreted and thrown out of the body as refuse. A cell consists of two main parts, known as *nucleus* and *cytoplasm* (pron.: si'-to-plas-um), in peculiarly vital relation to each other. The protoplasm of the nucleus is different from that of the cytoplasm, and is known as *nucleoplasm*. Both fluid or "sol" nucleoplasm, and cytoplasm can and do turn at need or on injury resulting, for example, from heat into solid "gel" forms.

Chemically, protoplasm consists of proteins, of which an example is the egg white we have already mentioned. Proteins are extremely complex bodies which science has never yet contrived to build in the laboratory. A molecule of a protein may weigh two or three thousand times as much as a molecule of water. Water is made up simply of two atoms of hydrogen and one atom of oxygen. This structure is expressed in the chemical formula H_2O. A protein is of enormous complexity, being built up principally of carbon, oxygen and nitrogen, with smaller amounts of hydrogen and sometimes of sulphur. It is expressed in formula as $C_{55}H_7N_{16}O_{24}S_2$ and it is asking a lot of even modern science to build such a chemical

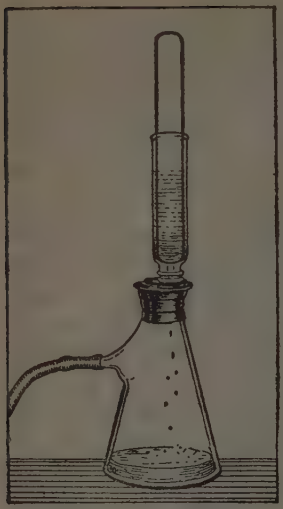


Fig. 2. *A virus filter.*

We have a very ingenious method of detecting viruses—by filtering them. Every one knows how particles are retained in a sieve. Well, imagine a sieve with infinitely small holes in it. Such filters have been found, and can be graded to catch various bacteria. The finest filters will hold back all bacteria but not some minute particles which, for all their smallness, can cause diseases. Such a particle is known as a *filterable virus*.

You see one of these filters in Fig. 2. The fluid is poured into

structure as this! The proteins in the cell, and in the human body, are all built from comparatively simple substances called *amino-acids* (pron.: a-meen-o), the bricks, so to speak, that, when put together, form the magnificent chemical palace that is a protein molecule. But we shall learn more of these amino-acids, when we study metabolism.

The simplest forms of life that we know of are viruses, and though so infinitely small that perhaps we shall never be able to see them, these specks are of great interest to man.

Owing to the nature of light itself—the fact that it travels in waves—it will, as far as is at present known, be impossible to see an object smaller than one hundred thousandth part of an inch in diameter—even with the best possible microscopes. Most viruses are about one two-hundred and-fifty-thousandth part of an inch in diameter.

Fig. 3. *Hydrophobia attacking brain cells.* (a) *Inclusion body in diseased cell.* (b) *Degenerating cell nucleus.* (c) *Healthy cell.*

the glass mantle which surrounds the hollow "candle" of the filter. This is connected with the flask from which all air has been sucked out, thus creating a vacuum. So the fluid outside the "candle" is sucked through into the flask. The virus will pass through with it—but larger particles such as bacteria remain outside the candle in the glass mantle.

Viruses are of such importance to us because they are responsible for quite a number of infectious diseases; samples are rabies in dogs—or hydrophobia in man—smallpox, measles, chicken-pox, infantile paralysis (perhaps the smallest virus of all, being about one million five hundred thousandth part of an inch in diameter), and (as many think) the common cold.

It is very difficult to say exactly what happens in the body when viruses invade it. But the great genius of Pasteur discovered that in time the body develops a reaction to the virus within it—so becoming immune. It was by working on this principle that he discovered the treatment for hydrophobia in dogs and men, and it is due to him that the disease is nowadays almost unknown in this country.

The virus of hydrophobia attacks the nerve cells of the brain, and in Fig. 3, you see inside the diseased nerve cell a speckled shape, known as an *inclusion body*. This may represent unusual growth of the virus itself, or, as others hold, be derived from the living cell in its battle with the virus.

From this brief account it will be seen that there are very many puzzles still be solved regarding the viruses, but with bacteria we are on firmer ground.

Bacteria are very small masses of protoplasm. They are not divided into nucleus and cytoplasm as in an ordinary cell—though sometimes there is a suggestion of this. They exist in myriad millions around us. They are swarming on your skin at this moment. They are in your ears, nose and throat in countless numbers. But although some are capable of producing disease, others and perhaps most, are helpful in maintaining health. It is an error, which must be corrected from the first, to think that all bacteria are man's enemies. On the contrary, it is quite true to say that without bacteria man could never have

Fig. 4.

evolved. For it is bacteria which are largely responsible for breaking down dead animal and plant life into those simple substances which we know as manure, and which are essential for the growth of the plants on which all animals, including man, depend. In Fig. 4 you see small round growths on the root of the vetch. These are formed by colonies of bacteria which help the plant assimilate nitrogen. It is bacteria that ripen cheese, and produce leather, and a hundred other important processes in the world's everyday life.

Seen under the microscope, bacteria have very varying shapes and sizes. You see some of these in Fig. 5. They have definite shape, because on the surface there is what is known as an *envelope*, which usually is a relatively tough *pellicle*. Sometimes there is a clear *capsule* (Fig. 5, Part. I, B) outside this. Some of them have, attached to their bodies long, fine, wavy processes, which they use as oars. These are called *flagellæ* because they whip like a flagellator—but not for the same purpose! In Fig. 5, Part I, A, you see these flagellæ attached in various different ways. The bacilli of typhoid fever are of this type, and swim about contentedly in milk or water, in this way carrying infection to any one who drinks them.

MAIN TYPES OF BACTERIA

The main types of bacteria are *cocci* (pron.: kok-si), bacilli, *spirillæ*, *spirochætes* (pron.: spi′-ro-keets) and *vibrios*. These are seen in Fig. 5, Parts II and III: the round cocci, the rod-shaped bacilli, with and without flagellæ, the corkscrew-shaped spirillæ, and the more

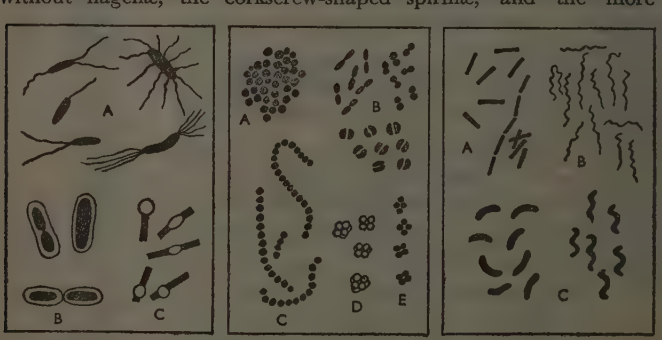


Fig. 5. Part I. (a) *Bacteria with flagellæ, such as typhoid.* (b) *Encapsulated bacteria.* (c) *Bacteria forming spores. Part II.* (a) *Staphylococci.* (b) *Diplococci.* (c) *Streptococci.* (d) *Sarcinæ.* (e) *Tetrads. Part III.* (a) *Bacilli.* (b) *Spirochæte.* (c) *Vibrios and spirillæ.*

delicately waved spirochætes. When the round cocci stick together in groups, they are known as *staphylococci* (Fig. 5, Part II, A) —from the Greek word *staphylos* meaning a bunch of grapes— and this is exactly what they look like. These staphylococci are natural inhabitants of the skin but sometimes invade the body, and are the cause of boils and carbuncles. When the cocci run in chains they are known as *streptococci* (Fig. 5, Part II, C). These are responsible for many human ailments from scarlet fever to puerperal, or child-bed, fever.

THE LIFE STORY OF BACTERIA

The life story of a bacterium is short and usually not very eventful. The whole story from birth to death lasts about one hour. During this short space of time nourishment has been taken in from surrounding fluids, in some cases oxygen has been breathed, the bacterium has waxed bigger, until the time to reproduce arrives. Bacteria have no sex. They reproduce by the simple expedient of dividing into two. It is worthy of reflection that if one bacterium divides into two, every hour, at the end of a day there will be over sixteen million—if they all survived, which fortunately they do not.

But this is not the only course of life for a bacterium, for if outside circumstances become unfavourable—say the temperature drops, or the moisture so necessary to bacterial life, dries up—then a bacillus develops a thick round gelatinous swelling known as a *spore* (Fig. 5, Part I, C). In this form it may survive for many months or longer, at a temperature below freezing point, to turn back again into an ordinary bacillus when conditions improve. This very remarkable device enables bacteria to live through all kinds of unfavourable climates, and incidentally makes it sometimes very difficult to stamp out an epidemic.

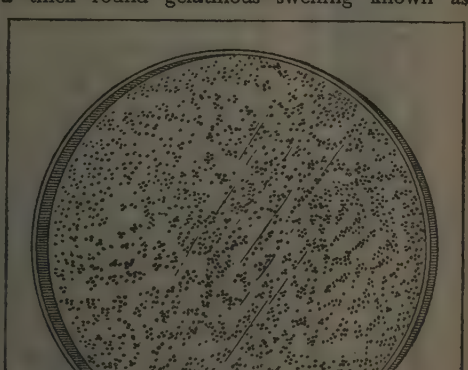
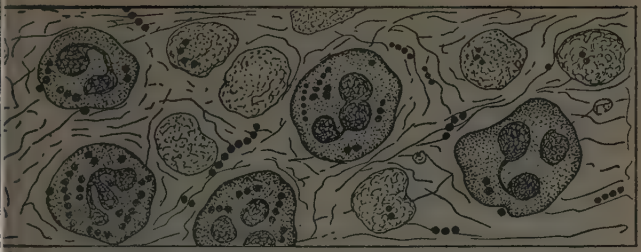


Fig. 6. *Bacteria being bred on a glass petri dish.*

The favourite conditions for growth of bacteria are, moisture, plenty of protein and sugar, and a temperature of about thirty-seven degrees centigrade—body heat. Bacteriologists for this reason utilize all these points when they grow bacteria in their laboratories, in order to study their properties. Glass dishes with covers (*petri dishes*), such as you see in Fig. 6, are taken, and made " sterile " or free from all bacteria. Then a melted " medium " is poured into the dish and allowed to cool. As it cools it sets hard. One of the best " media " is *agar* mixed with blood. When this sets bacteria can be planted on it, by smearing on the medium some of the material to be investigated. The dish is then put into an incubator at a temperature of thirty-seven degrees centigrade. In twenty-four hours " colonies " of bacteria are scattered over the surface as in the picture. Some bacteria, however, will grow where there is hardly any oxygen. The bacillus of *anthrax* is one. If a test-tube of gelatin is " stabbed " with an infected needle the bacillus grows in the gelatin and liquefies it. The straight line in the illustration (Fig. 7) shows the track of the needle, from which radiate the lines of liquefaction like the branches of a fir tree. And since oxygen is necessary, though in only small amounts, this liquefaction is wider at the top of the gelatin than at the bottom.

Fig. 7. *A "stab culture" in gelatin.* (*See text.*)

Of course, as regards the human body bacteria interest us most as carriers of disease. When the resistance of the body is lowered by underfeeding or fatigue, then it falls a prey to bacterial invasion, and becomes infected. Later on we shall discuss the methods adopted by the body to defeat the invader. But the most important of these is illustrated in Fig. 8, which shows " white " cells of the blood engulfing and devouring a group of streptococci—a process which was first noticed by a Russian scientist named Metchnikoff, who rather picturesquely stabbed a transparent water-flea with a rose-thorn, and watched what happened under the microscope. To his amazement he saw white cells like those in



g. 8. *Bacteria* (*streptococci*) *being devoured by white cells of the ood* (*leucocytes*) *some of which have degenerated, forming pus cells.*

e illustration, surround the rose-thorn and gradually devour it. ıe same fate overtakes the bacteria.

The next step upwards from bacteria is to cell forms. Cells are ing to provide the bricks, so to speak, of which the human body built. But they are not very simple bricks.

In Fig. 9 you see a typical cell. The whole of it is composed protoplasm (A)—the essential basis of life. In the centre is the ıcleus separated from the cytoplasm by the *nuclear membrana.* : the side a small body (C)—*the centrosome* (pron. : sen'-tro-soam)—lies.

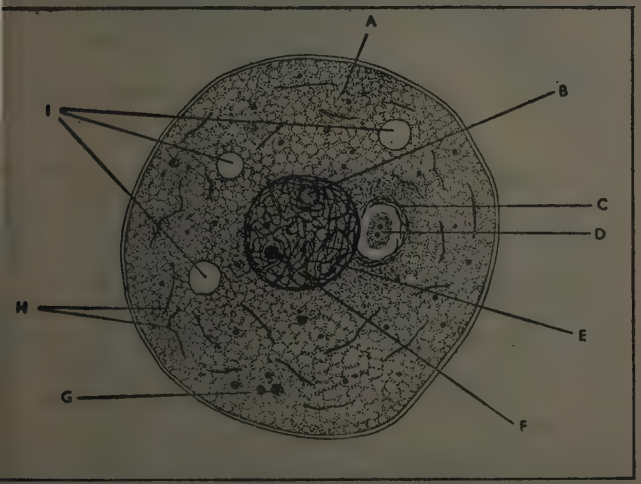


Fig. 9. A single cell of protoplasm. (*For lettering, see text.*)

This contains two small bodies (D) which play a vital part when the cell divides. Inside the nucleus there is a *nucleolus* or minor nucleus (B). The dark colour of the nucleus is due to a substance *chromatin* (pron.: kro'-mattin) (E), which collects into *nodes* (F).

In the cytoplasm lie many granules of foreign material, which are either being taken into the substance of the cell (assimilated) or being cast out (excreted). Round holes or *vacuoles* (I) form some round food particles, some as a method of excretion. There are also small globules of fat (G), and a number of structures in the cell whose function is not understood. The *mitochondria* (pron. mi-to-konn-dry-a) (H), for instance, are plentifully scattered through the cell though no known function has been found for them.

Fig. 10. *A typical amœba.* (*For lettering, see text.*)

All cells possess the characteristics of life which we mentioned earlier: movement, metabolism, growth, and reproduction; as also the power to respond to a change outside it—a stimulus. This irritability though very variable in degree, is present in all cells.

Protozoa is the name given to organisms that consist of but one cell. Of these undoubtedly the most interesting is the amœba. This humble animal lives in the mud of ponds. A large amœba would be just visible to the naked eye. When looked at under the microscope the amœba is seen as shown in Fig. 10. There one sees the outer envelope of clear *ectoplasm* (E), inside which flows the fluid cytoplasm (D)—the essential life protoplasm of the organism. Somewhere near the middle a denser portion is seen—the nucleus—which is the vital centre of the amœba (A). If the amœba were cut into two, so that the nucleus lies in one fragment—that

rt will live and produce new cytoplasm, but the other fragment ll die. In the living amœba, clear spots appear in the cytoplasm, d get larger and larger until they suddenly burst. These are *con-ctile vacuoles* (B)—the amœba's device for excreting liquid waste oducts—just as humans excrete urine. If our amœba under the icroscope were alive, we should see it moving restlessly to and fro search of fresh food to devour. In order to change its position, rt of its body flows out in a certain direction—this is called a *eudopodium* or pseudo-foot (one is marked at H). Eventually e whole of the amœba's body, or cell, flows into this pseudopodium, d the amœba has moved. This process continues until it has ached its destination. Slow but sure is the motto of the amœba.

HOW AN AMŒBA FEEDS

Suppose, in the course of its journey, the amœba comes across small particle of food. Let us watch the way it takes a meal. he slow-moving cell flows up to, and round the morsel, com-etely engulfing it, usually in its hinder part. The food particle w lies in the endoplasm, and around it appears a layer of clear, gestive juices—a food *vacuole* (C) (pron. : vak-yoo-oal). In this way e food is assimilated or incorporated in the amœba—indigestible rticles are cast away. Note that the amœba does not go through is procedure with *any* particle it happens to meet, but chooses ose suitable as food. How such a simple organism performs is feat of selection it is very difficult to say. Even how the amœba eathes is not very clear, for within the single cell there is no ecial mechanism detectable for this purpose, but probably ygen permeates the cell from outside.

THE RUSE OF LIVING DEATH

Like some of the bacteria, in unpleasant circumstances the nœba turns itself into a round thick-walled blob, a cyst (pron.: t). Here it can live for a long time, and revive when it finds itself ain in a suitable environment, such as a pond. This trick of spended animation is a favourite of nature's. Here, there is sign of life—no respiration, no water intake, and yet months ter there is a resurrection and the animal leads its normal exist-nce. A similar process occurs in higher animals; hedgehogs bernate and frogs stiffen in their winter holes, queen bees lie coma in their underground retreat. Something different from rdinary sleep, this suspended animation is one of the many nanswered riddles of nature presented to us by the amœba.

Reproduction in the amœba is usually simple. When it has rown bulky a split forms and deepens, eventually dividing the cell nto two in such a way that equal parts of nucleoplasm (F) are resent in each section. So that an amœba never really dies, for

it does not give birth to its daughters like humans—it *is* its daughters. Thus is the problem of immortality solved in this humble example of life!

The amœba has been described in some detail for three reasons. First, it is a typical cell in its structure and mode of life and, however complex our description of different cells in the body becomes, the root principle of living will always be as in the amœba. Secondly, there are in the body, cells which are almost identical in their movement, structure and habits with the amœba—the white cells of the blood, which engulf irritant particles in the body, particularly bacteria. Thirdly, one form of amœba sometimes invades the human gut, where it feeds on the tissues so causing deep ulceration. This amœba is the cause of "tropical dysentery." Other amœbæ may inhabit the human gut but do not cause disease.

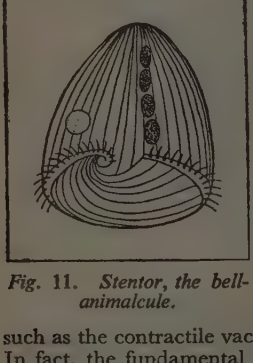


Fig. 11. *Stentor, the bell-animalcule.*

The amœba represents the simplest unicellular organism, but elaborations and variations in both structure and mode of life are almost infinite. There are the *bell-animalcules* or *stentors*, for instance. These single cells seem fashioned like a bell when seen from outside, as in Fig. 11. Sometimes by a handle to the bell, they fix themselves on to stones and weeds. Round the rim you see the *cilia*, by which they swim through the water. A food-tube runs from the surface down into the body of the cell, food particles being whirled into it by the action of the cilia. Other parts, such as the contractile vacuole and the nucleus, are like the amœba. In fact, the fundamental pattern of the cell is the same; but how different the mode of travelling, of fixing itself to solid supports—and also, incidentally, of reproducing itself!

We saw that an amœba grew larger until it was top-heavy, and then simply split down the middle into two parts. Very often stentor adopts this method, too. But under certain conditions, usually those which are unfavourable to easy life, stentor changes its plan. Instead of dividing into two equal daughter cells, a lot of small cells are formed—identical with the parent, except very much smaller. These small stentors swim about until they find one of the longer stalked kinds and then become attached—the pellicle of ectoplasm becomes absorbed, and the nuclei split up into particles which pass from one to the other. Finally, the *endoplasm* of the smaller partner is drawn up into the larger. What has happened? The nuclear material of two stentors has fused together

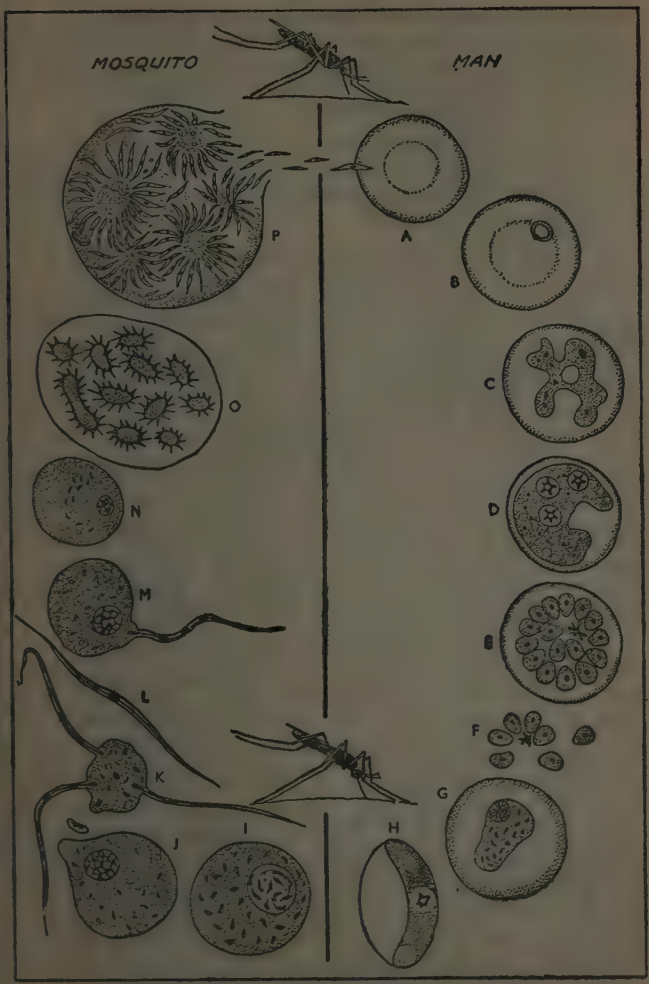


Fig. 12. The malarial cycle in man and mosquito.

to produce a third, different from either of its parents. Sex has arrived! When we look again we see that the two parent cells really have faint traces of active and passive, of male and female about them, even in the humble stentor, and the fusion of their nuclei is the very essence of sex.

THE MIRACLE OF THE MALARIAL PARASITE

The third example of a unicellular organism that we shall glance at is the malarial parasite, responsible for bearing disease rampant through the tropics and even to these British islands until about two hundred years ago.

This single cell has adapted itself to a very peculiar life. It is a parasite on man and mosquitoes—doing no good to either.

The parasite enters man when the particular mosquito bites. Soon, in the blood stream it enters a red blood cell, as you see in Fig. 12 at A. Here it is in comfortable surroundings, and grows larger and larger (B and C), until it occupies nearly all the space available to it (D), when it divides. It is not two daughter cells that are produced, but several, perhaps ten (E). These *merozoites*, as they are called, now burst out of the red cell into the blood (F). Each starts out on a search for another healthy-looking red blood cell to invade—and very soon the whole process repeats itself. Now, strangely enough, the process of growth always takes the same length of time. For example, one type of malarial parasite always takes forty-eight hours to grow, and produce a new outburst of the little merozoites, which is the signal for fever. So it is that a patient with this type inside him, gets an "attack of malaria" every third day. This is called "tertian" fever.

HOW THE PARASITE REPRODUCES ITSELF

But one can well see (taking the malarial parasite's point of view) that it cannot stop here, for gradually these merozoites will get killed, and the story would come to an end in the human. This is the problem which has to be solved. The solution is astoundingly clever. When the merozoites are getting sluggish—a new kind of parasitic cell is noticed to develop in the red cell of the blood. It may be round (G), or sausage-shaped (H), but it lies there, nourishing itself in the blood cell, until one day, a new and possibly uninfected mosquito bites, when it is sucked up, and eventually finds itself in the mosquito's stomach. Here it invades the wall and these strange sausage-shaped and round bodies develop into sexual cells, that is to say male (J) which develop long active flagellæ (K), and female, larger, round and inactive (I). The flagellæ can become detached (L) and die. Normally, however, the small male cell (or *gamete*) (pron. : ga'-meet) lashes about until he comes into contact with a female, and fusion takes place (M).

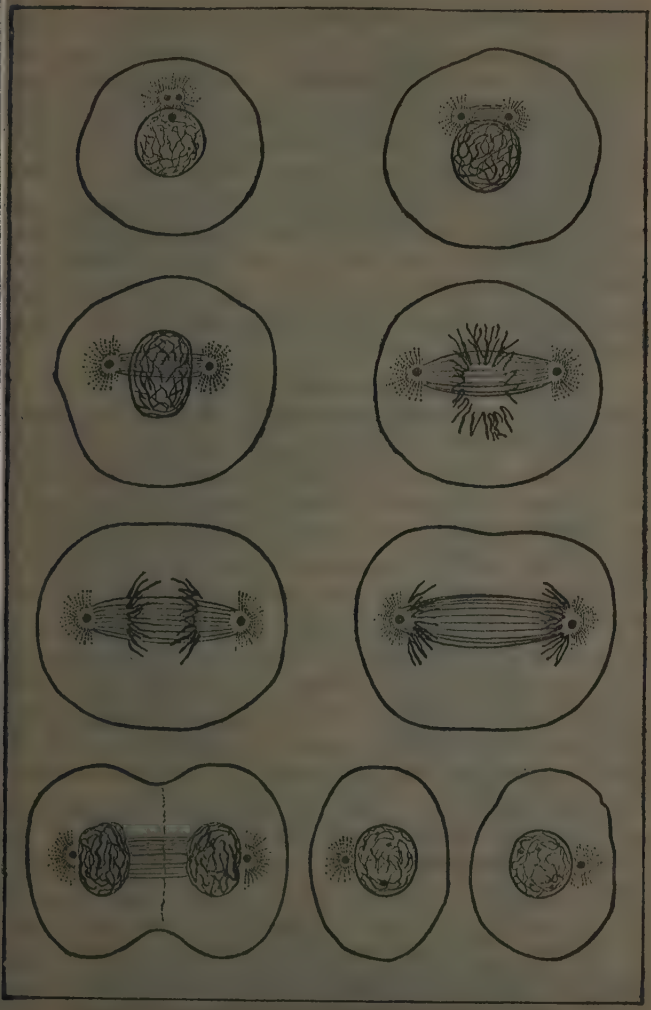


Fig. 13. *Various stages in the division of a single cell.*

This is the process of fertilization, and is the same in whatever animal it occurs. The next generation is now formed, and the little creature (N) forms a round swelling in the wall of the mosquito's stomach, still sucking its nourishment from the mosquito. Here it divides as you see into hundreds of slender pointed cells (O), tightly packed together. These break off and travel to the *salivary gland* of the mosquito, and at the next mosquito bite, a good dose of malaria (P) is injected into the human victim. A new red blood cell is found, and the whole cycle starts again.

It is a complicated story—that of the malarial parasite, but it leaves one with a sense of admiration at the ingenuity by which one simple cell keeps its place in the battle of life, defying extermination—at least until very recently. For now man is learning ways of breaking the cycle, chiefly by destroying mosquitoes and their *larvæ*, so that we hope to see malaria become as rare a disease in the tropics as it is in England.

INTER-RELATION OF CELLS

We have so far glimpsed the lives of three cells which live to this day as organisms on their own. But the cells which form the human body cannot do this. An amœba solves in its little body all the problems of feeding, metabolism, excretion, and many others. In the human body, however, each cell fits into a mosaic and so one function develops at the expense of others. Take for example contraction. An amœba can contract—a little. A muscle cell of the body can contract—enormously. But to gain this advantage the muscle cell needs a large supply of a special diet and must obey orders from controlling nerves. Left on its own the muscle cell would soon die. And finally, muscle cells cannot reproduce themselves—even in the human body. This alone means that they are useless as competitors in the struggle of evolution. The muscle cell of the body compares with an amœba in the same way as a professor of mathematics with a savage—both the muscle cell and the professor will die if they are deprived of the necessities of their special surroundings, and are plunged into an entirely primitive life, which is natural to the amœba or the savage.

But cells in the body do, of course, reproduce—so that the body shall grow, and repair the wear and tear of everyday life. The ritual of cell-reproduction in the body is another masterpiece of nature. You see the stages in Fig. 13, and notice that the whole process essentially concerns the nucleus, which is dark because it contains a substance known as *chromatin*. Outside the nucleus is the *centrosome*. First the chromatin in the nucleus arranges itself in a thread, while the centrosome, outside, divides itself into two each half wandering to opposite poles of the nucleus. From them radiate their filaments of protoplasm. The thread of chromatin

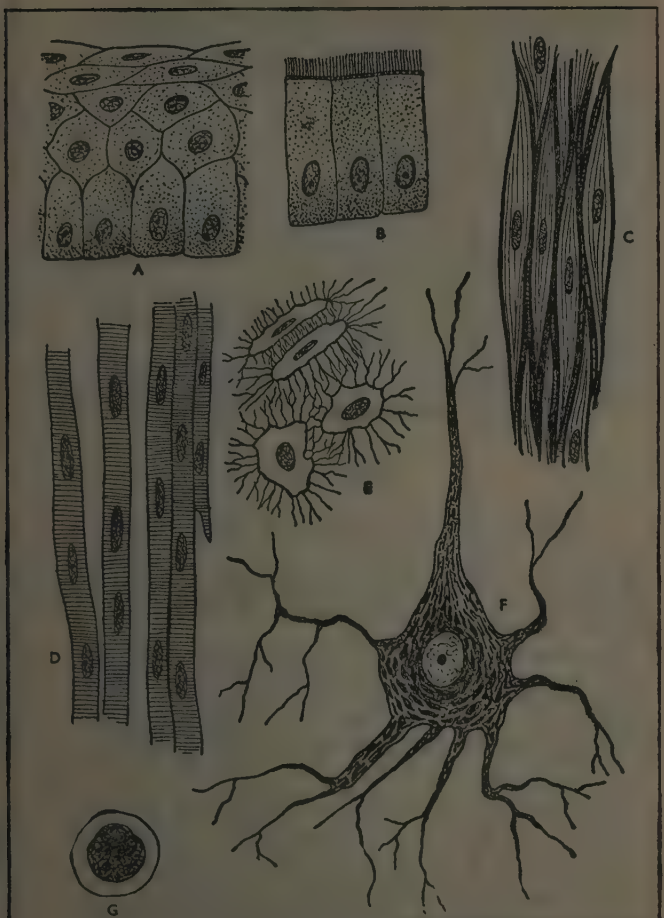


Fig. 14. *Typical cells of the human body.* (a) *Cells from mouth tissue.* (b) *Tissue cells with filaments.* (c) *Smooth muscle cells (involuntary).* (d) *Striped muscle cells (voluntary).* (e) *Bone cells.* (f) *Nerve cell.* (g) *A specialized blood cell known as a lymphocyte.*

breaks itself up into a number of rod-shaped portions called *chromosomes* (pron. : kro-mo-soams). These range round the equator, like a set of hairpins. In this position they split and each hairpin wanders along the thin threads in opposite directions to the centrosomes. When this happens the cell cytoplasm gradually splits, and two new cells are formed, containing precisely equal shares, both of nucleus and cytoplasm, from the parent cell. This is the way the body grows. And, as the cells reproduce themselves, they change, until they lose their original simplicity and turn into all the varieties and more, which you see in Fig. 14. The long, powerful muscle cell for pulling, the delicate nerve cell for feeling, the rugged bone cell for strength—all these originally developed from a single cell the *ovum*, in appearance like an amœba, which was invaded by a *sperm* cell and began dividing, growing, and dividing again. Each generation is more specialized than the last until the human body is produced.

This germ cell—the fertilized ovum—which contains in its own small self the miraculous power of developing in nine months into a complete human being is surely the most wonderful in creation.

CHAPTER II

THE EVOLUTION OF MAN

JUST as in the last chapter we noticed that one cell can in nine months develop into a complete human being, so, in the course of perhaps three hundred million years life struggled on, until man was designed.

This process is known as *evolution*—an idea that seems very simple to us, but we must never forget that during the whole of the second half of the nineteenth century a battle royal was raging between the "creationists" and the evolutionists. In the United States of America, there are still regions where the rearguard action of creationism is being fought, where it is held that God created man as he is, and that fossils are the Creator's freakish whim.

In this chapter it is not our object to argue this point. We shall simply describe facts, and point out their relation to that great "unfolding" of life which is the essence of evolution. We shall describe how life has ascended, step by step from the lowly amœba to man; how the rocks bear evidence of this in a truly remarkable manner as shown by the fossils found within them; how animal structure is modified to suit special circumstances—and not produced ready, and perfected in design. We shall describe variations, some successes, some failures, out of which Nature has chosen the fittest for living—how these alone have survived while the others

have been rejected and cast into oblivion.

Life appeared on this planet, perhaps three to six hundred million years ago. For about a thousand million years the earth twisted round the sun a fiery, lifeless mass. Gradually it cooled and rocks appeared from the molten lava—rocks born of the flames, and for that reason called *igneous* rocks. Then as cooling went on, further layers, known as *strata*, were laid down. Soon the wind, rain and frost wore off bits of these hard rocks. Small particles flowed down in streams and rivers, until, when the flow became sluggish, they were dropped on to the bottom where they formed thick layers of mud. In time pressure from above hardened this mud into further rock, so that on top of the original igneous rocks lay the *sedimentary* or *stratified* rocks in layers. It is in these sedimentary rocks that fossils are found. The layers of sedimentary rocks are always in a definite order, one above the other, and the fossils contained in them are peculiar to each layer; as the layer of rock becomes more recent, so do the fossils contained in it become more complex. In the lower layers are simple fossils, in the superficial or recent layers they are highly developed.

These layers of rocks have names, which divide up the great embrace of time through which life has existed. In Fig. 1 you see these names, and in Fig. 2 pictures of the life forms that are typical of the later eras.

The earth has existed some two thousand million years. For half this time there was no life, as far as fossils show. This does not exclude the possibility that simple forms of life, which left no fossils, existed. In this colossal stretch of time, the *Archæozoic* (pron. : arky-o-zo'-ik) era life was in its very infancy. During the next five hundred million years life developed, and reached as far as worm

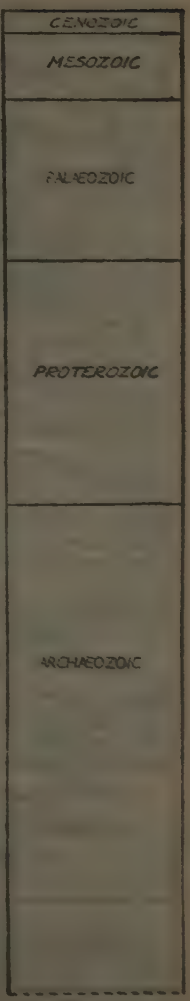


Fig. 1.

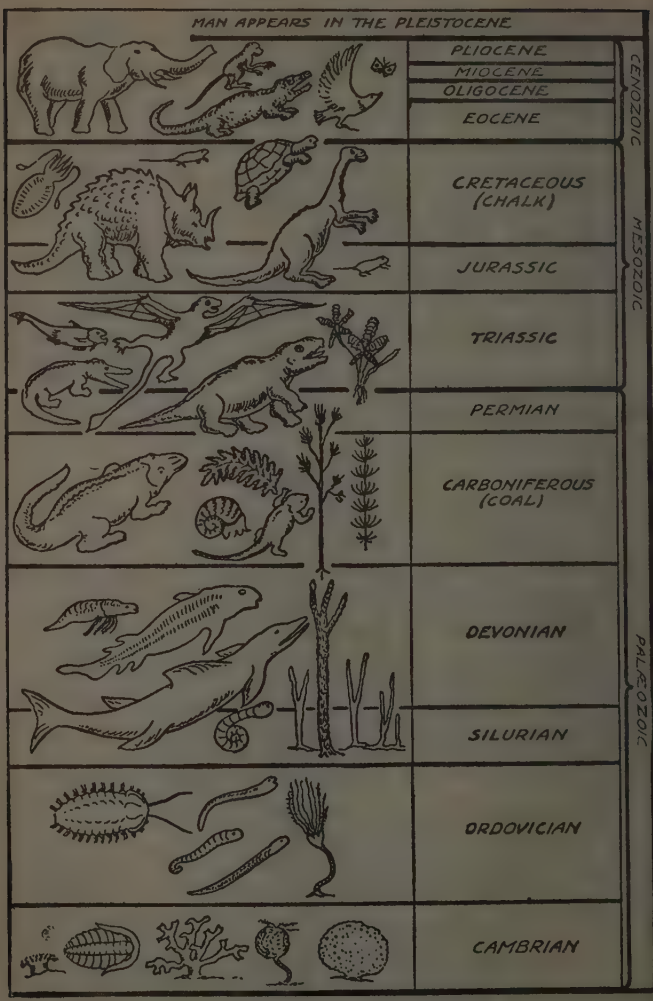


Fig. 2. Comparative stages in the evolution of life.

rms. This is the *Proterozoic* (pron. : pro-terr'-o-zo'-ic) era, during hich there were vast volcanic eruptions in one of which, incidentally he Grand Canyon of Arizona, U.S.A. was formed.

From this point we can trace life's development in more detail. n Fig. 2, you see a comparative scale showing the relative duration f various eras and periods, into which life's history can be divided. begins, at the bottom, with the *Cambrian* period of the *Palæozoic* ra, which began approximately five hundred million years ago, nd it ends with the *Pliocene* (pron. : pli'-o-seen) period of the *Cenozoic* ra. Here, as nearly as we can tell, man first appeared, some half- illion years ago. You will see that he is but the veriest new-comer n life's story, so recently arrived that his whole span up to the resent is scarcely visible in the scale. And you will remember ee Fig. 1) that life itself is a veritable recent arrival in relation the total age of the earth !

Let us now look at these various eras in life's story more closely.

THE PALÆOZOIC ERA

Following the Proterozoic, the next great era is the Palæozoic, n which is found a spate of developing life. In the first period of his era—the Cambrian—jellyfish, sponges and corals are in evidence, ut there were no backboned creatures (*vertebrates*). In the next, he *Ordovician*, vertebrates arise in the form of fishes. The third r *Silurian* period is noteworthy for another series of volcanic ovements by which dry, bare land was created in vast expanses, setting life a new problem of conquest. This change was accom- anied by a very dry climate which continued into the fourth or *evonian* period, during which the first fossil remains of an animal, hich walked on land, have been found. Life is coming out of the ater, its first home, and beginning to conquer the land. This eriod is called the " Devonian," because its most typical rocks are he red sandstone which is so conspicuous in Devon. Any one ho finds himself in that part of England should search the rock r fossils which abound. These are chiefly of fishes, and a combina- on of fish and lizard, the *ichthyosaurus* (pron. : ik'-thy-o-so'rus).

THE CARBONIFEROUS PERIOD

In the next, the *Carboniferous* period, *amphibians*, creatures that ve in both land and water, abounded. These beasts, sometimes he size of mules, walked about in these dense dark forests, which ater were to disappear beneath the soil and become the coal mines f the future lords of creation—ourselves.

In the *Permian*, the last of the periods of the Palæozoic era, eptiles first appeared. Not only did the climate become dry and rid, but Ice Ages of extreme intensity, particularly in the southern emisphere, took place. In response to this drought nature selected

the reptile which is well equipped for dry conditions. This was the age when dinosaurs developed (Fig. 3).

But the real age of reptiles is the next great era, the *Mesozoic*. Lasting about one hundred million years, this era saw the huge, armour-clad reptiles spread widely over the face of the earth. Some of them were about seventy feet long, and weighed forty tons or more. But these fearsome beasts became over-specialized; they lost their teeth and other essential portions of their anatomy. And then the climate changed again. They lasted through the great periods of this era—the *Triassic*, *Jurassic*, into the *Cretaceous* or Chalk period, during which they suddenly died out—and little, puny mammals, with only their large brains to indicate a future, timidly watched their huge ancestors fade out of existence. The victory of brain over brawn was near.

Fig. 3. *The dinosaur, typical denizen of the Mesozoic era.*

At last we enter the Cenozoic period—the age of mammals perhaps fifty million years ago. Birds also now flourish. Large expanses of grass appear. Flesh-eating mammals, hoofed mammals, monkeys—all gradually appear through the *Eocene*, *Oligocene*, *Miocene* and *Pliocene* periods, until finally in the *Pleistocene* comes man—in the hairy shape of Neanderthal man.

This short description summarizes then, the time framework of evolution, as told in fossil-writing in the Book of the Rocks.

But how does this process occur? What are the forces that changed amœba, obliterated the great reptiles, and created man? This was the question that Darwin answered in his book *The Origin of Species*. The idea of evolution is not new. The great Greek philosopher certainly suggested it. Aristotle, amongst other things a great naturalist, says: "Nature can only rise by degrees from lower to higher types." This over two thousand years ago! But it was Darwin who, in 1859, published the first account of how this ris

from lower to higher types took place. Let us read the summarizing paragraph at the end of *The Origin of Species*:

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing in the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other . . . have all been produced by laws acting around us."

Notice that he says "laws"—laws as true, as pitiless, as any law of physics or chemistry. These laws are—growth, which logically ends in reproduction; inheritance—with variation; a high ratio of increase, so that there is of necessity a struggle for existence, with its consequent survival of the fittest—which is natural selection.

DARWIN'S DISCOVERIES IN SOUTH AMERICA

What was the evidence that induced Darwin to conceive this great idea? We shall surely understand the process better, if we can follow him as he originally built up its structure in his own mind.

The first significant group of facts he found on his voyage in H.M.S. *Beagle* to South America. Here he discovered the remains of many extinct ground-sloths, predecessors of existing ant-eaters. He noticed how very similar these extinct forms were to those still existing. He wrote at the time: "This wonderful relationship in the same continent between the dead and the living, will, I do not doubt, hereafter, throw more light on the appearance of organic things on our earth, and their disappearance from it, than any other class of facts."

THE GIANT TORTOISES OF THE GALAPAGOS ISLANDS

It was in the Galapagos Islands that Darwin noticed strange facts about the giant tortoises. In ten islands, situated close together there were ten slightly different kinds of tortoise. Why had they not interbred and become one type within that small area? Because the sea was deep, the currents rapid, and not in directions to help migration. So that these similar tortoises had gone on developing in their isolation from each other. Then how account for their similarity? There could be only one answer. They must have had a common ancestor. The original species lived on a volcanic island. The volcano became active—the island became an archipelago, with the tortoises marooned on the various islands, on which they had been developing ever since. To clinch this theory, he found that nearly all the land lizards were similarly isolated and divided into types, peculiar to each island. But one which was a very strong swimmer, and could therefore get from one island to another, was the same throughout all the islands.

Geographical evidence of this kind abounds. But one cannot

but admire the genius of the man who first saw the solution of the riddle of the tortoises of the Galapagos Islands. Darwin's evidence from fossils was sadly incomplete in his day. Of this he was painfully aware. "Let us turn to our richest geological museums, and what a paltry display we behold!" he writes bitterly. It was because of this deficiency there arose so much chatter about "missing links." Very many of these "links" have been found. But Darwin filled the gaps with the aid of his powerful, controlled imagination, with the results that many of his forecasted types have been discovered. The great message of the fossils, that life gradually grew in fineness and delicacy, was true to Darwin.

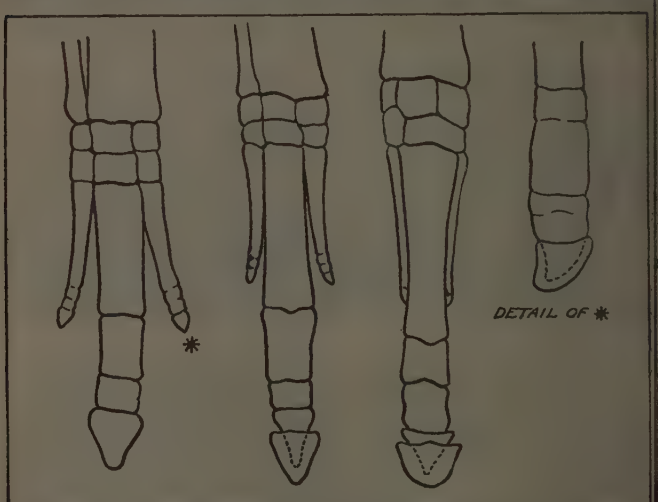


Fig. 4. *The development of the horse's foot through the ages.*

One example of this progress is beautifully illustrated in the evolution of the horse's hoof, which you see in Fig. 4. Primitive limbs all had five digits (fingers or toes); in the horse, fleetness of limb became of predominant importance on the grassy lands where food was to be found. So the horse gained length of limb by running on tiptoe. Gradually those with smaller side digits were naturally selected, because of that vital inch of length which gave swiftness. And you see the two vestigial, useless stumps that represent toes of the past, are still present on the horse's hoof.

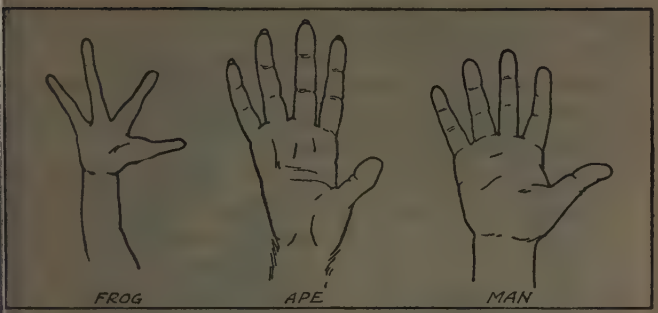


Fig. 5. Comparative hand structure in frog, ape and man.

This glimpse of the horse's past also introduces us to another ine of evidence, upon which Darwin set much store—the funda- nental patterns of nature. How is one to account for the fact that comparing the fore-limbs of frogs, bats, horses, apes, and men, they are all made on the same pattern? That this is a fact, you can see for yourself by a glance at Figs. 5 and 6.

How can this have come about except by modification from ome fundamental root-design? There is one answer—that the

ig. 6. *The wing of a bat and the forearm and hand of a man. The structural similarity is unmistakable.*

predecessor of birds, mammals and reptiles had its limbs fashioned on this general pattern, which has become variously adapted to the surroundings, in which the descendants found themselves.

A similar fundamental pattern is found to exist in the construction of the mouths of insects—in moths, bees and beetles, for example. Even the extraordinary structure of the elephant's trunk is gradually evolved from primitive nose and upper lip.

Perhaps some of the most fascinating evidence collected by Darwin, was that concerning "*vestigial*" structures. Have you ever considered what use are the buttons on the sleeve of your coat? There they are (Fig. 7), a relic of the days when sleeves buttoned tightly at the wrist. Today they are useless but they illustrate the history of making coats, that is, the evolution of coats. So it is with certain structures of the body, which are the last remains or vestiges of once useful, active organs. A number of these are shown in Fig. 8. Perhaps the best example is the third eyelid. In man, as also in most monkeys, this eyelid is represented by only a small remnant of tissue. But if you watch a bird you will notice how from time to time this thin sheet of skin sweeps across the eye and back again in a flash. The third eyelid was developed in order to clean the front of the eye. It is present in reptiles, persists in birds and also some mammals. But man developed much more free movement of his two, upper and lower, eyelids, and so dispensed with the necessity of the third, which gradually diminished or atrophied to its present insignificance.

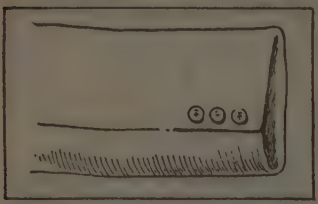


Fig. 7. "Vestigial" coat buttons.

Strangely enough it has also disappeared in the whales, probably on account of the fact that it was of no use in aquatic surroundings.

HOW SCALP AND EAR REMIND US OF OUR PAST

Again in the scalp and ear, there are reminders of our past. Every one has seen people who can move their scalps and ears. This capacity is due to the unusual development of superficial muscles which are present in apes. Darwin relates how in one family this useless faculty was transmitted through eight generations. The muscles of the ear (Fig. 9) are usually in man mere vestiges, compared with those which are found, say, in the horse. The reason is, that if a noise comes from one side man quickly turns his mobile neck, but the horse cannot turn so easily, and instead twists back the ear to catch the sound. In some men, however, these muscles that "twitch" the ear remain quite well developed and they can move their ears in much the same way as the horse,

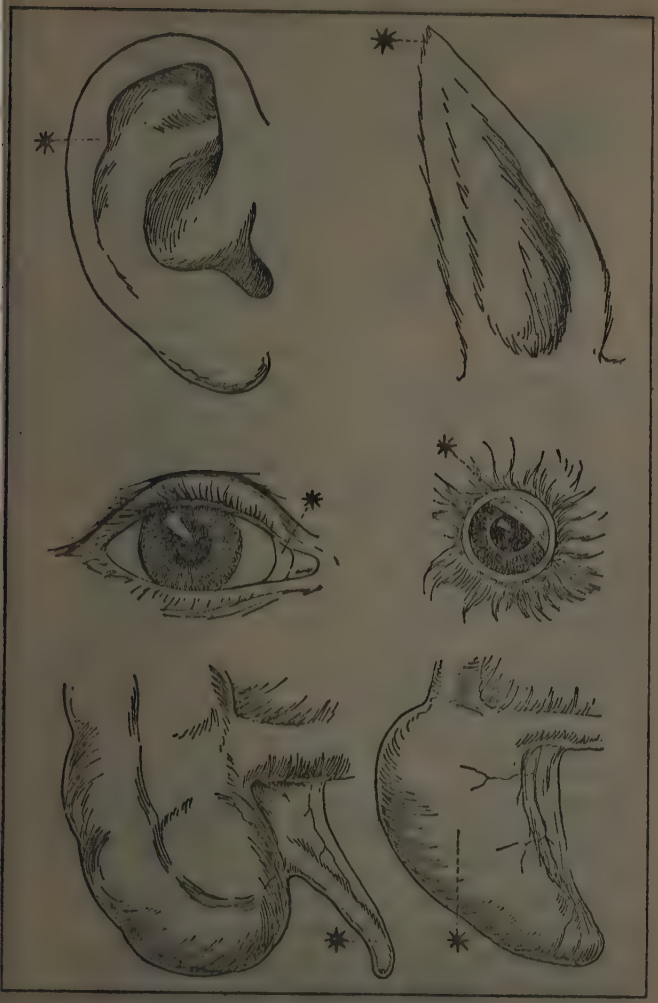


Fig. 8. *Examples of vestigial structures illustrating Darwin's theory.*

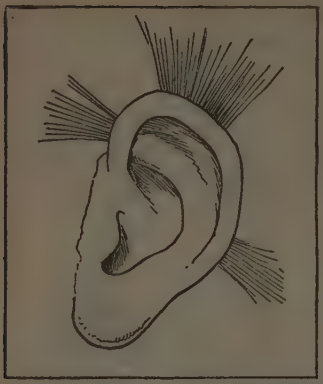


Fig. 9. The position of the primitive muscles of the human ear.

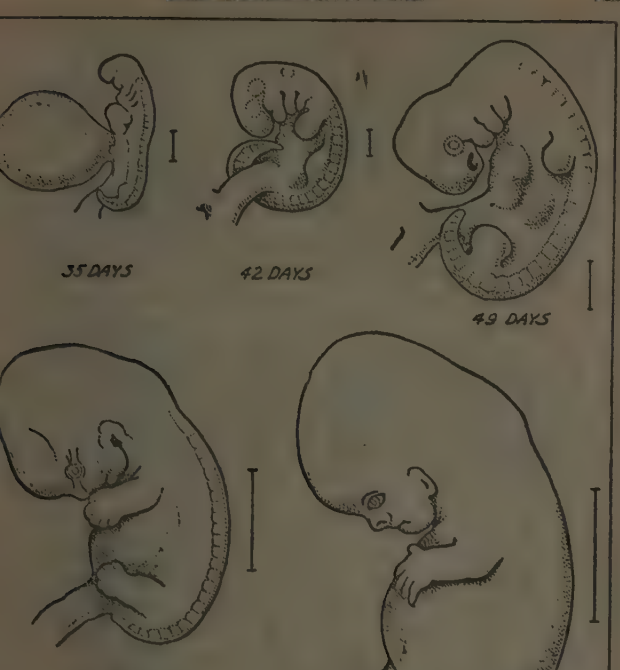
though possibly not so extensively

The many folded shell tha forms the ear is probably becom ing quite useless to man, an well on the way to becomin a vestigial organ. One interest ing point about the ear i illustrated in Fig. 8—Darwin' *tubercle* (pron.: tu'be-er-kel) Looking at the back of the to folded edge of the ear, yo will notice, in some people, blunt projection. This littl tubercle probably represents th apex of a pointed ear, as in rabbit—it is a reminder to u of our origin from ancestor with pointed ears, a charac teristic which artists are ver fond of allotting to Puck an the god Pan, who always represent the primitive spirit of man

Another interesting human rudiment is the body's hair. How poor is our "fur" as compared with cats, foxes or even mules! But such as they are, our hairs are fitted with complete muscular and nervous apparatus for "bristling." Often, when newly born, the human has a more or less complete downy coat—the *lanugo*—which does not, however, grow on the palms of the hands and soles of the feet; in this it mimics exactly the distribution of the coat in furry mammals.

The appendix—that organ which is so often the cause of serious illnesses—is also a vestigial organ; in fact, this may be one reason why it so commonly becomes diseased, for these structures have but little capacity to resist infection. In animals that live on vegetables and grasses (*herbivora*) there is a long blind tube called the *cæcum* (pron.: see'-kum) (Fig. 8). Probably as a result of change to flesh

Fig. 10. Man's tail.



11. *The development of the human embryo. The various stages are drawn to life-size and show how it re-enacts life's evolution.*

ng, this cæcum has become shrunken in man and a worm-like e about four inches long, the appendix, is all that remains. astly, we must mention man's tail. In the illustrations of eloping embryos (Figs. 11 and 12), you see the projecting tail, ch later disappears. If you follow your backbone down, at the you will come to all that is left of your tail (Fig. 10). In a few ortunate people this tail does persist after birth—fortunately a

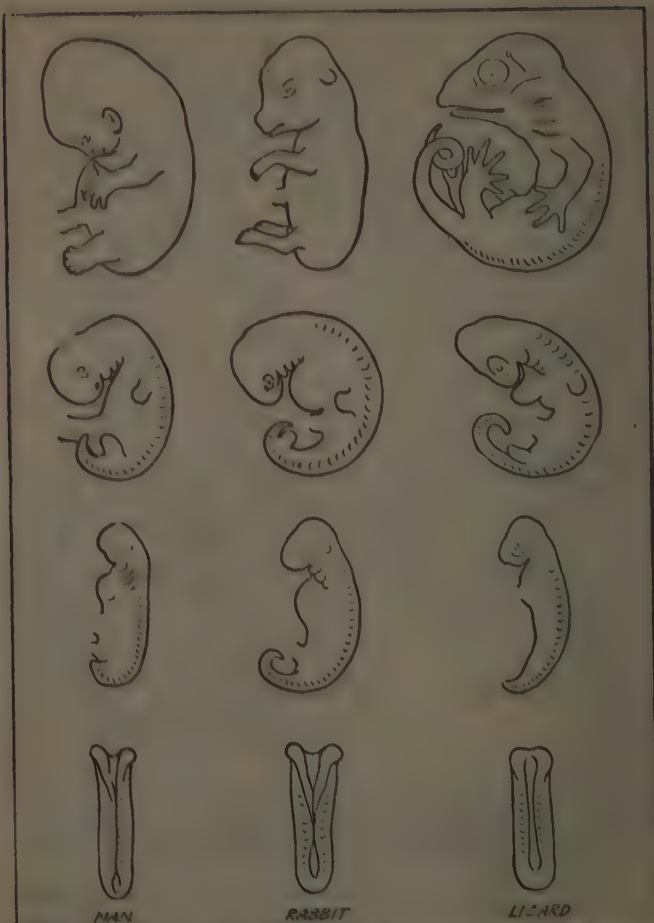


Fig. 12. *Four stages, seen from bottom to top, in the development before birth of man, rabbit and lizard. An astonishing similarity of design is evident until comparatively late in the ante-natal life of all three types, when they begin to develop their own specific features.*

very rare occurrence. Although the tail bones are all fused together into a single mass, muscles for wagging the tail are present still—but no one has been known to be able to use them, even to the extent of the muscles of scalp and ear we have already described.

All animal bodies start out on their journey of life as single cells. The human being commences as a fertilized egg in the womb or *uterus* of a woman. During the next nine months this cell divides and multiplies—increasing not only in size but in complexity (Fig. 11). As it grows, it passes through all the stages of evolution. Very early on, this embryo is like a worm in its structure. The whole body is divided into many segments like the rings of a worm. At the front end a brain is developing and a spinal cord runs down the back of the tube to the curved tail, giving off branches to each of the sections.

DEVELOPMENT OF THE HUMAN EMBRYO

Then the worm turns into a fish-like body. Gill-slits develop at the front—blood vessels run through these gills—just in the same way as they do in fishes—the only difference being that these developing gills are never used, for the necessary oxygen is derived from the blood of the mother. At this time too, the limb begins to develop in front and behind. Lungs and heart develop in front of the primitive food tube—until they have a pattern just like that of a frog, the gills disappearing and being built into the back of the throat and the ear. Even in adult humans, there is a tube which connects the back of the nose with the ear, accounting for the way you sometimes hear a click on swallowing. This tube itself, is a remnant of a gill, a reminder of your fish-like ancestors.

EVOLUTION AND EMBRYOLOGY

And so, passing through a reptile stage, the little embryo in the womb becomes a little mammal—quite indistinguishable for some time from the tailed embryos of rabbits or lizards (Fig. 12). Then gradually the brain develops and a great similarity to the apes appears.

Near birth this resemblance is diminished slightly, and the human infant takes on for the first time a shape that is unique to itself.

What is the point of this curious process in development? As we saw, the gills are quite useless—why then should they appear? It can only be that the embryo is going through the history of life in itself, and is building itself up on this evolutionary scaffolding. This process alone drives one to the alternative—"Evolution or Magic?"

To illustrate this parallel between evolution and *embryology*, let us describe the development of the face—always an interesting, if not always beautiful, part of the body.

First of all, the face developed at the front end of the body—why? If you imagine a simple tubular animal like a worm moving with one end always first, this part will come into contact with strange objects. It therefore developed special apparatus for detecting these things. For this reason special nerve centres developed, so forming primitive brains. Food (the most important of the strange objects met with) also, was taken in at the front end, so that organs for detecting it, such as nose and tongue also appeared. Thus a face has been defined as "the food detecting and food trapping mask in front of the brain."

Mouths and small pigment spots sensitive to light exist in single-celled animals, but real faces perhaps appear only with fishes. If you look at a dog-fish's head, you will find it composed of *cartilage* or gristle, with no bone on it. There is a mouth and eyes and nostrils connected with the mouth. Compare this with the embryonic face, with its strange wide clefts from eye to mouth.

THE DEVELOPMENT OF MAN'S SKULL

Gradually real bones were laid down on this gristly basis (which in man forms only the floor of the skull), and at the same time a sheet of muscle extended from the neck up over the face and skull. It is from this that the power of moving parts of the face and scalp developed—this sheet of muscle was the material for expression of the emotions. As the eyes developed and conveyed their multitudinous messages to the brain, and the ears and nose did likewise, this central relay station grew bigger, so that a forehead appeared and the eyes swung round to the front of the head. Meanwhile the jaw altered. Originally designed for catching and rending prey, the jaw was long and powerful. But as tree life became the habit of the pioneering mammals, the fore-limb became used for grasping instead of running—the animal became erect and the jaw was left for chewing, not catching, its food. So it began to recede. Then as voice took on importance, sounding chambers developed forming most of the "cheek" of higher apes until man's face appeared. The muscles we use for expression are all primitive. In sneering we use the same muscle as a dog uses for snarling to expose his fangs. And how much do our habitual emotions frame themselves in the expression of our faces!

Man's similarity to the apes is nowadays so commonly recognized, that the shock that rocked the world when Darwin's *The Descent of Man* was published, has been almost forgotten.

A glance at the illustration of the two skeletons of man and a gorilla (Fig. 13), at once suggests relationship of some kind. Darwin also points out, that apart from the many anatomical resemblances, there must be close similarity in minute structure and even in chemical composition. This latter statement, which must have

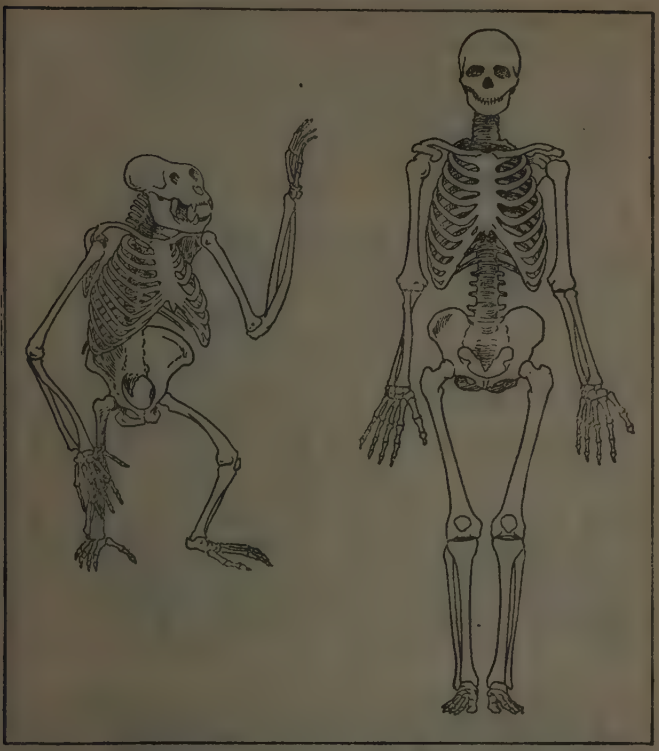


Fig. 13. *The skeletons of a full-grown gorilla and a full-grown man.*

been in the nature of a guess on Darwin's part, has received striking confirmation in recent years. It has been found that deposits are formed when bloods of two quite different animals are mixed —and the more different the species of each animal, the more the deposit. A test—the *precipitin test*—has been worked out whereby any smear of blood can be traced back to its animal of origin. This test, incidentally, is sometimes used in the detection of crime. By this means the relationships of different animals have also been clarified. Man's nearness to the anthropoid apes has again been verified, as has the closeness of orang-utans to gorillas. This chemical similarity of man to apes is again illustrated by the

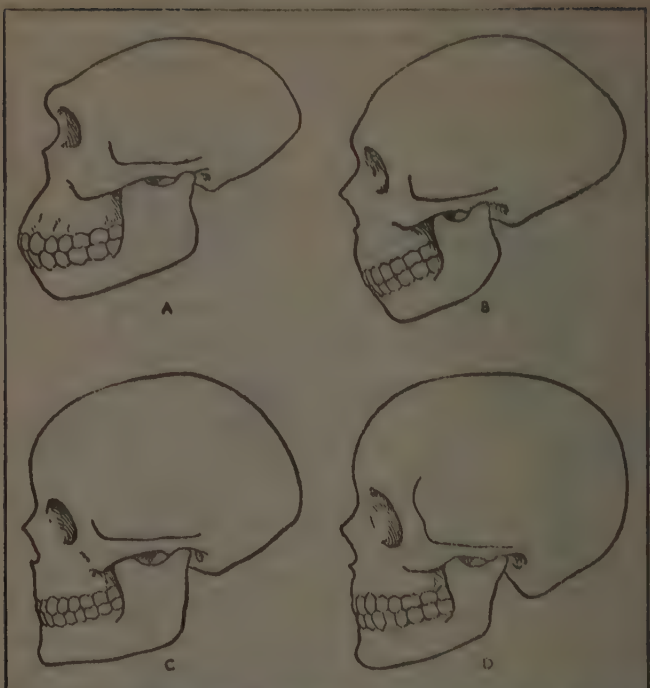


Fig. 14. *Four types of human skull, showing its evolution from the earliest man-like being* (a), *through later stages* (b *and* c), *to modern man* (d).

tendency to suffer from similar diseases, and also by the similar response of both to drugs.

Let us get our facts quite clear here. When we say that man is closely related to the apes, we do *not* mean that he is descended from them, any more than you are descended from your cousin. We mean that both apes and man had common ancestors. Perhaps this relationship will be made clearer by looking carefully at this particular branch of man's evolutionary tree (*see* FRONTISPIECE), where you see the common stock of primates divides, first giving off a branch which gives rise to the apes and monkeys, the remaining branch developing into man-like forms.

In Darwin's time there were few links between ape and man.

These have been filled up astonishingly since his death. Fig. 14 shows four stages of the development of the human skull. In 1891 a skull, thigh-bone, and teeth were found in Java. Sir Arthur Keith has described the being that owned them as "human in stature, human in gait, human in all his parts, save his brain." *Pithecanthropus erectus* (A), a name meaning upright ape-man, is midway between anthropoid apes and man. The other bones found with this ape-man were those of extinct mammals of at least a quarter of a million years ago.

NEANDERTHAL MAN

In 1908, near Heidelberg the lower jaw of another ape-man was found, buried with mammoth and woolly rhinoceros. This jaw shows a slightly higher type than the *Pithecanthropus erectus* (pron.: pithy-kann'-thro-puss). Then in 1912, the *Piltdown* man was discovered. Argument still swirls round the interpretation of these bones—but the brain of this man being larger, he is thought to be worthy of the title *Homo*. Sir Arthur Keith calls him "the earliest Englishman we know of as yet."

Neanderthal man (Fig. 14, B) discovered in 1856, has been found in various parts of Belgium, Spain and France. This type probably overlapped *Homo sapiens*, and is thought to have been an unsuccessful experiment. One can imagine *Homo Neanderthalensis* (pron.: nay-ander-tal-enn'sis), clumsy and heavy, about five feet tall, silently shuffling about his cave. He has lit a fire there to roast his evening meal. There he sits on his powerful haunches over the fire, his short muscular hands, covered with hair; his large head and low forehead with prominent eyebrow ridges, shakes to and fro as his heavy jaws chew the tender flesh of today's kill.

CRÔ-MAGNON MAN

In 1921 the *Rhodesian* man was saved from the pickaxe of a negro labourer by the quickness of a mining engineer—by such chances is the cause of science served. This Rhodesian man forms a link between Heidelberg and Neanderthal man and is of great importance. Incidentally, he was found to have suffered from dental decay, as well as accompanying arthritis, so providing some 120,000 years ago a lesson in medicine as well as anthropology.

Let us end our brief survey of these borderland men with mention of the *Crô-Magnon* (C) men, who between the Ice Ages of the early Pleistocene period re-inhabited the caves of Neanderthal man. These men were thoroughly worthy of the name *Homo sapiens*. Physically, they were indeed more beautifully proportioned than modern man (D). They had larger brains. Their faces had lost the protruding jaw and receding forehead, and taken on the stamp of intelligence. In their caves they left vigorously-coloured paintings

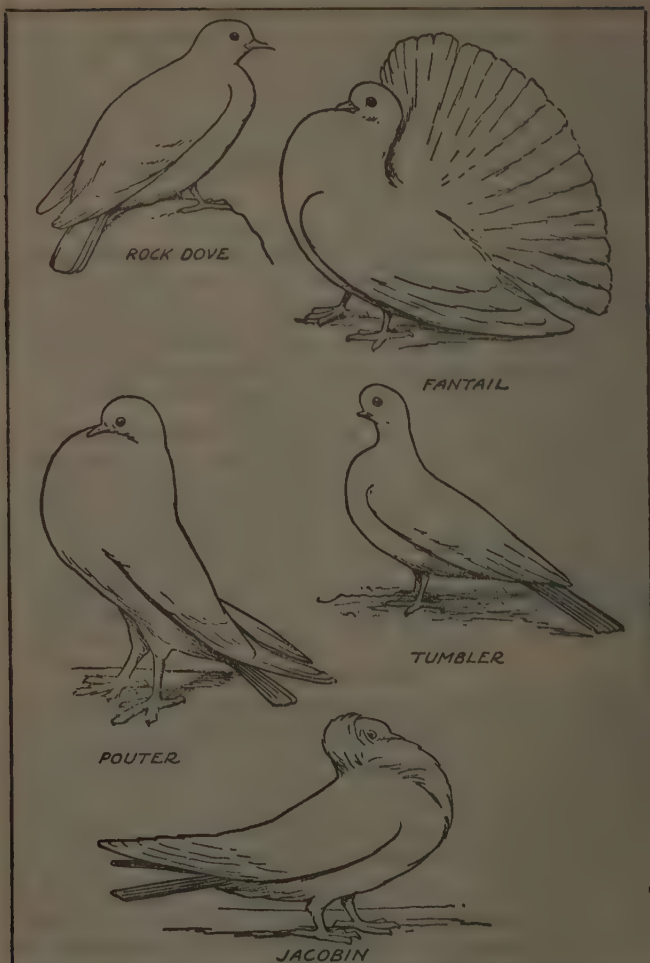


Fig. 15. *Man's influence over evolution. Types of doves and pigeons all developed, by artificial selection, from the primitive rock dove.*

—and even sculpture. When they were evolved, man had stepped out of the shadows into the light.

But how did man emerge from the ruck of his fellow-mammals, leaving them behind, and later mastering them?

Probably the main factor in this is his brain development. The brain of man, particularly the front part, is far and away more developed than in other mammals, and this in correlation with his mental capacity. Herein lies in some way, his capacity for thought, speech and morality, which essentially raise him above other mammals. For on these basic capacities civilized society is founded, and it is as a social animal that man has triumphed. Individually he is relatively puny, he cannot run very fast, he is not hardy—but collectively, as a part of a social unit, it is another story. Again, with such a large brain there is the relatively long infancy and childhood of man's life, longer in proportion to the whole life-span than in any other mammal. This gives great capacity for learning—for using the recently-acquired brain.

THE LAW OF VARIATION

We have so far described, of necessity briefly, some of the steps taken in the great procession of animal types from amœba to man. We mentioned how Darwin formulated laws of natural selection from evidence, less complete in his time than today.

In the light of these facts let us try to understand these laws, the most important of which concerns the problem of variation.

We all know how similar one man is to another—but equally well we know that hardly any two men are exactly alike. Of all the hundreds of faces we have seen, how many have been identical? This fact of variation has been of the utmost importance. For if some slight change has been found of use to an animal, then that animal tends to survive where those without it fail. We all know how these variations or peculiarities tend to be inherited—passed on to the next generation. Perhaps the best illustration to show the importance of variation, is the breeding of domestic animals, such as pigeons or doves. Here man, by the careful selection of birds with good points produces descendants which gradually improve, until at length the perfect example of a prize-winning pigeon is obtained. All the types of birds shown in Fig. 15 have been bred from the simple rock dove shown at the top. Note that this " perfection " is by man's standards, not nature's, and as soon as that pigeon is out of man's sight, primitive traits will reappear in the offspring. But natural selection, though slower, is just as thorough and produces changes as radical in the animal concerned as man's efforts; in fact much more so.

Now, by virtue of the fact that we all have parents, the importance of heredity becomes obvious. By it, not only are some variations

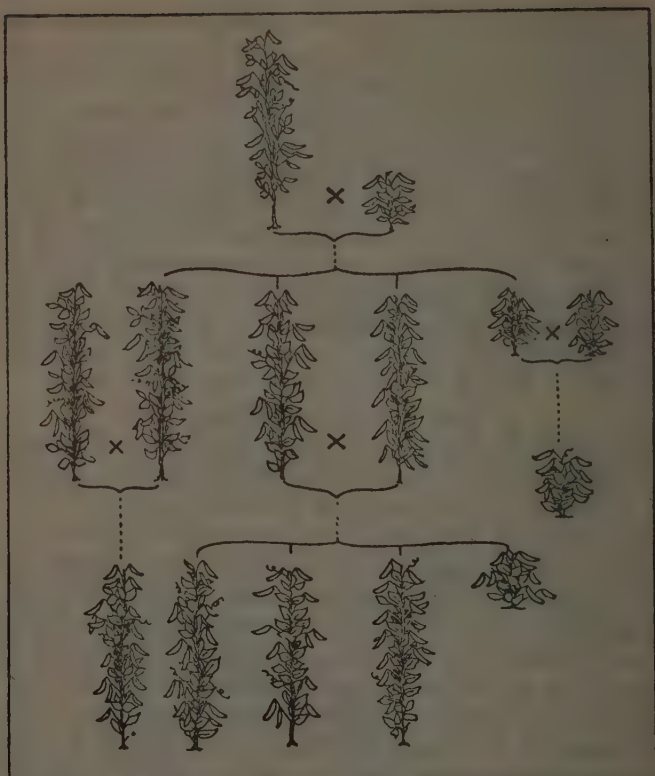


Fig. 16. *Diagrammatic illustration of how the characteristics of two types of peas are reproduced in their descendants.*

transmitted, but in others tendencies to vary are counteracted.

One's natural inheritance is all one starts out with in life. Therefore " a man cannot be too careful in the selection of his parents," as Heine put it. Since heredity influences the presence or absence of variation, let us see what we know of its mechanism.

It was on this work that the Abbé Mendel attained immortality. In his quiet monastery garden he studied the results of crossing various types of peas and beans, and worked out the laws of

inheritance of various characteristics such as colours, height, etc. He found that some characteristics, if present, always dominated others, and showed in the next generation, whilst others were overshadowed. Characteristics as regards heredity can be divided into what are called *dominant* and *recessive*.

In Fig. 16 the results of breeding from a pure tall pea and one of the dwarf variety are seen. In the first generation the proportions work out as one pure tall, two mixed, which, containing the tall, that is dominant characteristic, look just the same as the pure tall one, and one dwarf.

If now the pure tall pea is fertilized by another of the same type it will go on producing tall peas indefinitely as on the left of the figure. But the other two tall peas possess a recessive dwarf characteristic, so that if they are cross-fertilized they will again produce offspring in the proportions of three tall to one dwarf, and so on.

Finally, if the dwarf pea is mated with another dwarf the seedlings will be all dwarfs because in this case there is no dominant tall characteristic to overshadow the recessive dwarf one.

THE DOMINANT COLOUR CHARACTERISTIC

The presence of colour is always dominant to a lack of it, so that albinos will only be produced when both parents contain the "lack of colour" characteristic. If one contains the colour characteristic, this will always dominate the lack of colour and the result of their union will be normally coloured children.

These characteristics have been traced down to particles called *genes* (pron.: jeens), in the chromosomes in the nucleus of the human cell. One can imagine these genes strung like beads along the string of the chromosome (Fig. 17). Each little bead represents a characteristic, though some of them are linked together and do not separate. Any variations found in these genes in the germ cell—the ovum or *spermatozoa* (pron.: sper-matto'-zoa)—will be conveyed to cells of the next generation, and so tend to pass down indefinitely in time. There must, for example, be some reflection in the germ cell of the Hapsburgs, of the characteristic chin and lip which has stamped the family for hundreds of years. Night blindness is another characteristic that is represented in the genes. It has been known to follow the laws of Mendel in one family since the time of Charles I.

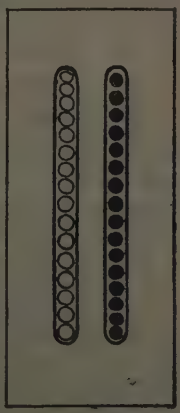


Fig. 17.

By the inheritance of progressive variations

the elephant elongated his upper lip and nose to get his trunk.

Can acquired variations be inherited? This vexed question is still being argued. In the usual way the answer is no. Though a blacksmith may develop enormous arm and chest muscles by virtue of his work, he does not produce an infant Hercules! Are we to assume then, that variations result purely by chance, as Darwin held? It seems difficult to believe this, and ever since Lamarck in the eighteenth century, there has been a strong body of opinion arguing that acquired changes do affect the germ-cells in some way, so reproducing these variations in offspring. This would be possible, for example, by the action of some chemical substance.

THE INFLUENCE OF ENVIRONMENT

The *struggle for existence* suggested by Darwin arises out of the high ratio of increase, which is present amongst all animals, man perhaps being the only one to give signs of being an exception. As a result of crowding, some members of the species get pushed out of a favourable environment into less ideal surroundings. Here they will either disappear, or by virtue of unusual characteristics survive, and even thrive. This would form a typical example of natural selection. Again, in the course of time some variations will arise more suitable, than those possessed by the original inhabitants, to the climate and environment, and the original species is conquered and killed. On the other hand other variations may make life almost impossible at all. These we call monsters—they are soon eliminated from the competition of life. But in a way the monster is very closely allied to the genius who is an equally strange variation from the normal and as much a thing of chance, which no one can foresee.

SIGNIFICANCE OF SEXUAL VARIATIONS

Darwin himself attached great importance to variations of sexual significance such as the plumage of birds. His idea was that the female selected the best mate only, so tending to reproduce the best offspring. Not only this, but features which developed as secondary sex characteristics, such as plumage, antlers, etc., were turned to other uses, and so aided the animal in its struggle for existence.

There is no doubt that when sex first appeared in unicellular animals it increased possible variations in the offspring by uniting in one cell all the characteristic genes of two parent cells. But sex has also fundamentally affected animals and men in the evolution of the mind. The voice was at first only used to produce a sex-call, as it is in the croaking of toads at present. From this beginning has evolved the whole magnificence of language and speech.

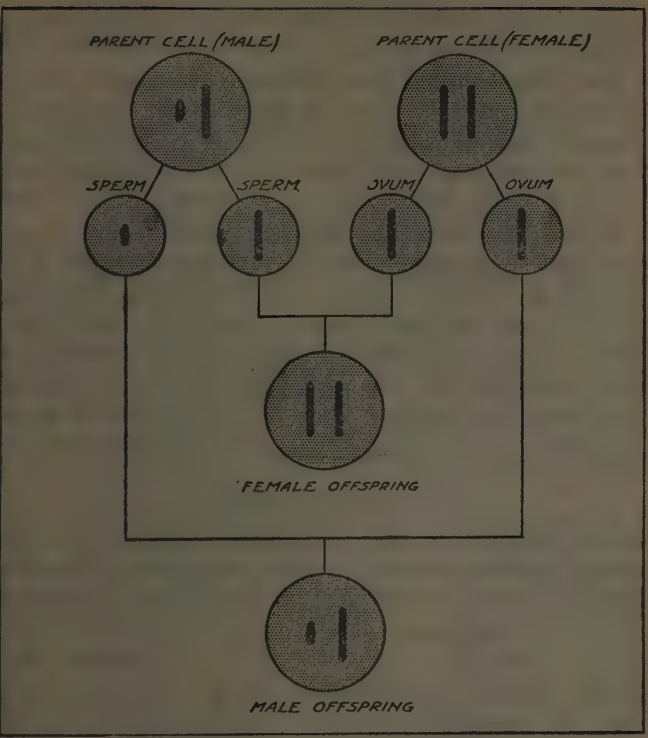


Fig. 18. *Simplified diagram of the law of inheritance.* (*See text.*)

There are also certain characteristics or genes which are linked in inheritance with the sex-chromosome. In Fig. 18 you see the cells containing two chromosomes. Those with the small or Y chromosomes are male, those with two large, X, are female. So that since these chromosomes are shared out in the reproductive cells one sperm will have a large or X chromosome, one a small or Y, whereas both the ova will contain large X chromosomes. What sex the offspring will be is therefore a matter which the male sperms decide, for if one with a large chromosome unites with the ovum, then the offspring has a full complement of large X chromosomes and becomes a female, like the female cell (top right of

figure). But if a sperm containing only the small or Y chromosomes unites with the ovum then a cell containing two unlike chromosomes (XY) is formed, which is male.

Now theoretically the sperm containing the large X chromosomes should be larger than that containing the small one. In fact, measurable differences are said to have been found. The possibility arises, therefore, that if one could devise a filter of the right mesh size, one might be able to strain off the large sperms containing female chromosomes, and let through the smaller male containing sperms—so producing boys when desired.

But other characteristics are sometimes carried with the sex genes and so are said to be sex-linked. This particularly applies to the bleeding disease (*hæmophilia*) (pron. : hee'-mo-fill'y-a). Supposing a diseased male marries a normal woman. Then his X chromosome will be present only in his daughters—not his sons, who will be normal—as you can see from Fig. 18. Now if this daughter with the unfortunate X chromosomes marries a normal man, the possibility is that a daughter will contain it and be a carrier, or a son have it and be a "bleeder." Note that it is also possible for the chromosomes to combine so that the evil X chromosome is not included, producing a healthy female or male child.

IS MAN STILL EVOLVING?

It is often asked whether evolution applies to man now, as to other animals. Do the laws of natural selection still apply? The answer is neither yes nor no. For man has so profoundly altered his environment that the meaning of the word "fittest" is changed. Fittest for what? is the question that must be asked. Until man arrived on the world-stage, animals that survived were those fittest to combat such difficulties as climate: heat, cold, winds and rain—in whatever combination presented. Obtaining food and warmth were the main considerations, even of the first wandering tribes of man. But gradually these elemental difficulties have been solved (at least partly) by the progress of civilization, by trade, commerce and science—until they form but a minor consideration in a man's life. His intelligence is now free to be devoted to his job, to learning or even to art and science, and the conscious study of his own conditions—politics.

No longer does each man fight his individual battle for life—he depends on other fellow men, each to do his special part, whilst he himself takes a portion of what they produce and provides his own contribution in return. For example, if you think how a loaf of bread reaches you, you realize how many people you depend upon for it.

Evolution of man does not deal so much with individuals any more, except in so far as illnesses and accidents are concerned.

It is nations that take their place, differently planned societies which clash or blend depending upon psychological, economic and political factors.

Man has introduced purpose into evolution. He works, so it is believed, for peace, happiness, and the welfare of individuals. But it remains to be seen whether the nations can reconcile their conflicting purposes, or whether they will abuse all that science has given them, and use it for that form of mutual extermination called war.

WHITHER EVOLUTION?

This leads us finally to the logical question—whither evolution? There is no doubt that up till now evolution has been a clumsy process—albeit very efficient. Mere survival, because of a chance useful difference, is a very slow way of obtaining improvement in life's handiwork. But by this method consciousness and mind have been evolved. For the first time evolution has become aware of itself—like a child growing up. So that now, perhaps, we shall be able to decide what is universally desirable for humanity in the future, and work for it consciously instead of by accident.

Some, including Bernard Shaw, like to think that all the way through there has been a vital force at work, striving for perfection, and that this will still modify the changes to come.

Others conceive of life struggling upwards, forming ever more integrated "wholes," in that a cell is a more perfect "whole" than a crystal. Through human beings, with mind, morals and consciousness, evolution will perhaps rise to what we would call God-like forms. Perhaps, indeed, God is the logical goal of evolution.

CHAPTER III

BONES AND FLESH

THE fundamental difference between plants and animals is that, whereas the former obtain their nourishment from the air and soil around them, the latter have to hunt for it. This means that animal structure must be adapted to free movement. There must, therefore, be a light framework of levers with bands that contract to work them, so that the animal can move from place to place in search of prey. Nature's best solution of this problem was bone and muscle.

It was not the only solution, however, for in one great group of living things, the *arthropods*, of which the lobster is a good example, the skeleton, or rigid framework consists of a hard box

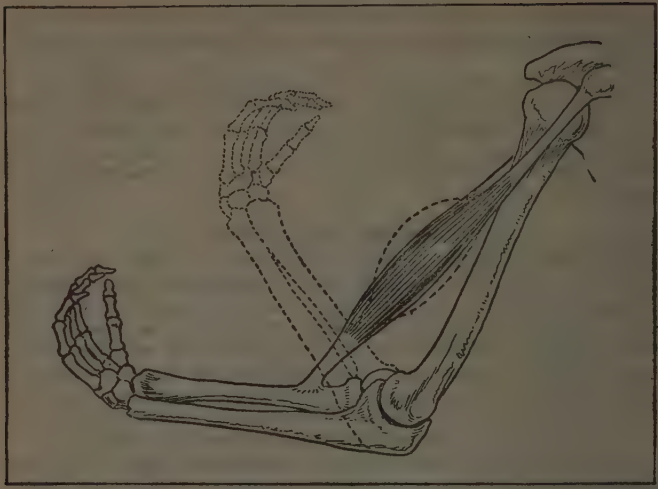


Fig. 1. *The elbow, showing how the muscles shorten when it is bent.*

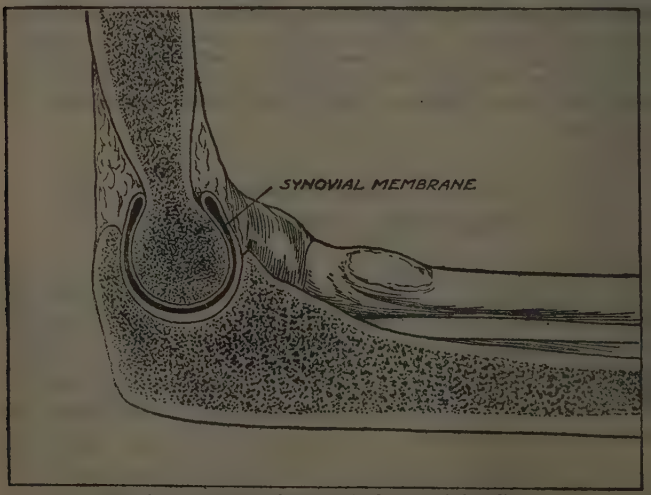


Fig. 2. *A section through the bones of the elbow.*

with the muscles working inside, as one can see on examining a lobster's claw. This is not at all like bones as we know them. Rather is it a modification of skin, ingenious in combining defence with mobility—but insufficiently so as it turned out, for the lobster is one of nature's failures.

But in birds and mammals up to man, the skeleton is laid down deep inside the body, forming a rigid framework, around which the flesh is laid. This flesh consists, for the most part, of muscle and fat. Muscle is the " lean meat " which we eat at meals. Its function is to " contract," in doing which the body of the muscle shortens, so bringing its two ends closer together. These two ends are attached to different bones, by specially tough, ropy " tendons." The two bones concerned come into contact, or " *articulate*," at joints. Here they move on one another, so that at a joint the bone is covered with a layer of smooth, white, glistening material-cartilage. Any joint, where there is friction, must be kept oiled, or lubricated as in a machine. This is done in the body by surrounding the joint by a bag of delicate tissue known as the *synovial membrane*. This tissue secretes the fluid for lubrication as required—a very neat solution, which man-made machines have never quite equalled.

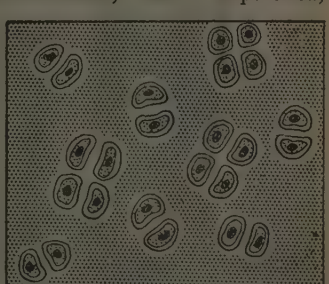


Fig. 3. *Cartilage under the microscope.*

A glance at Figs. 1 and 2 will at once show the part these various components take in moving one bone on another, in this case the arm-bones round the elbow-joint.

We must first describe the structure of cartilage, bone and connective tissue, in a little more detail, before considering actual parts of the body.

Cartilage is a peculiar tissue which is found in various parts of the body besides the ends of bones. It is in the windpipe, the nose and ears, and in all these parts forming a resilient firm basis to fragile structures—for example, in the windpipe, this elasticity helps to keep the tube always open, so that air can pass along it easily. A very interesting fact is that in the *fœtus* (pron. : fee't-us) (the infant in the womb) almost all the skeleton is laid down in cartilage, which is afterwards replaced by bone, except for the parts remaining at joint surfaces. Certain fishes, such as the dog-fish are entirely made of cartilage, and it is interesting to reflect that our own bodies at one time shared this characteristic.

Under the microscope, as seen in Fig. 3, cartilage reveals itself

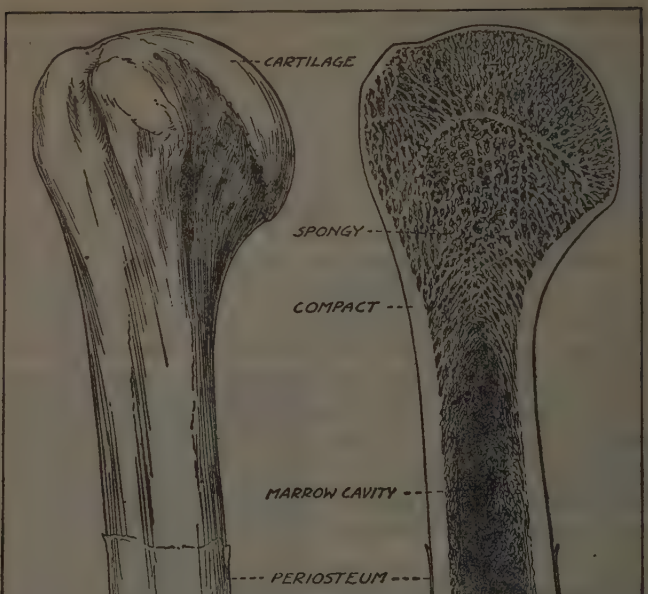


Fig. 4. *The upper end of the humerus* (left), *and a section* (right).

as groups of cells arranged in twos or fours, and separated by what is known as intercellular material, of a perfectly even pearly colour. This material has been secreted from the cells—just in the same way as tears are secreted from glands in the eye. When the cells divide they cannot part from one another, being imprisoned in this material, and so they are grouped together, as you see. There are no nerves or blood vessels in cartilage, and nourishment has to seep through, sometimes for a distance of inches, from blood vessels that supply the outer surfaces. It is because of this poor blood supply that cartilage does not stand injury or disease well.

Bone is the toughest tissue of the body. The structure of individual bones varies somewhat with their function, for example some are flat plates, others hollow tubes. But all bones are built, not only to bear mechanical stresses and strains, like the girders of a building, but also as factories for the output of the blood cells.

This rather surprising function of bones is one example, of which we shall see many, of the ingenious way nature utilizes her

opportunities to the full. It has been found, in constructing pillars for buildings, that a hollow tube bears stresses and strains better than a solid one—it is less likely to break, or fracture. So that in making bones hollow, nature has lost none of the mechanical efficiency and has at the same time used the space as a factory for blood cells.

In Fig. 4, you see the shoulder end of the upper arm-bone—the *humerus*. The smooth white end is the cartilage which forms part

Fig. 5. A sectional view of the upper end of the thigh-bone. The small diagram shows, in a simplified way, how the layers of spongy bone inside are arranged to bear the weight of the body.

of the shoulder-joint. The bump you see in front, beside a groove, is pulled out by the " insertion " of a muscle tendon at that spot. The groove is formed by the tendon of the biceps muscle, which is illustrated in action in Fig. 1 bending the elbow. Bones are shaped therefore to quite a degree by the muscles connected, or inserted into them, as well as by their inherited design.

If one cuts across this bone, one sees (Fig. 4) that the outer shell is very dense, like ivory. This is called " compact bone." Within this there is a looser arrangement, where shelves of bone cross at angles, giving an appearance like a honeycomb—known as spongy bone. These shelves are arranged, however, in such a way as to meet the particular strains put on to the bone, as shown in Fig. 5.

In the centre of the bone is the marrow cavity, filled with cells forming the blood and fat. This is described in a later chapter.

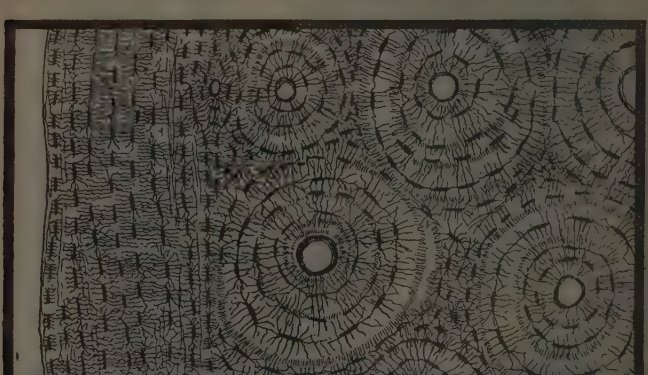


Fig. 6. A cross section of bone seen under the microscope.

Each bone is wrapped in fibrous tissue, called *periosteum* (pron. : per-ry-oss′-ty-um), which is important in its growth and in its repair after disease or injury, because it contains cells which build bone. For this reason it is thick and full of blood vessels in young people, but becomes less so as age advances.

Under the microscope, bone shows the appearance of cells arranged in circles around central spaces (Fig. 6). These cells occupy spaces in the surrounding bone which lies between them. The central space cut lengthways is seen to be a tube (Fig. 7). All these tubes form a network in the bone, through which the nerves and blood vessels run. They are known as the *Haversian canals*.

Chemically, bone is composed of about one-third animal matter

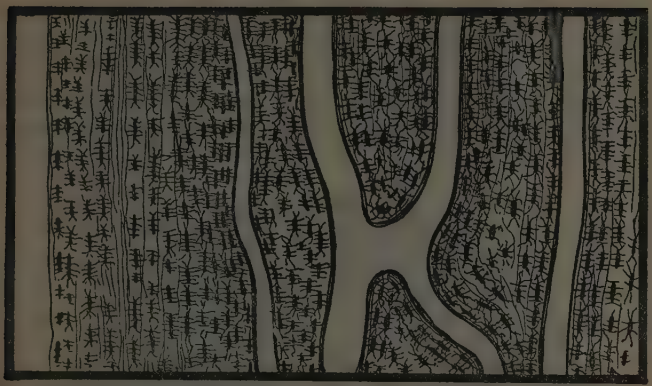


Fig. 7. A longitudinal section of bone seen under the microscope.

and two-thirds mineral—in the form of *calcium phosphates*. So that a bone soaked in dilute acid, which will rid it of its mineral constituent, becomes quite soft—and can even be tied in a knot! While the calcium phosphate gives it its hardness it is the cell material that adds elasticity and "spring."

Ossification means simply the process of forming bone. Some bones, such as those of the side of the head, form bone from ordinary fibrous tissue, but most are formed from a previous deposit of cartilage. For instance, in a long rod of cartilage (Fig. 8) a centre of ossification (A) appears in the middle and spreads towards both ends, leaving these unaffected, so that they form *articular* surfaces to the joints. Later on in life small centres of ossification (B) appear in these cartilaginous ends. These are called *epiphyses* (pron. : ep-pi'ffy-sees)—they are most important in growth, for as long as there is a layer of cartilage—known as the epiphysial line (C)—present between epiphysis and main shaft, the bone can and does grow. This means that in the case of leg-bones, they get longer, and so the whole body gets taller. But at varying ages from about fifteen to twenty-five these epiphyses close—the cartilage disappears, and no more growth is possible. The body has "grown up."

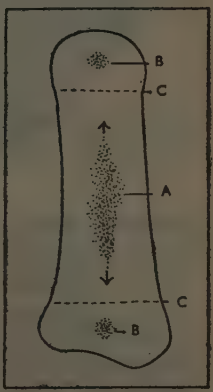


Fig. 8. The growth of a bone. (See text.)

Under the microscope this ossification is even more strange (Fig. 9). The cartilage cells first enlarge, later they shrink and calcium is deposited round their dead bodies. Then two new types of cell invade this land of the dead. One kind builds up true bone—the other destroys it. They are therefore called *osteoblasts* (bone builders or formers) and *osteoclasts* (bone eaters).

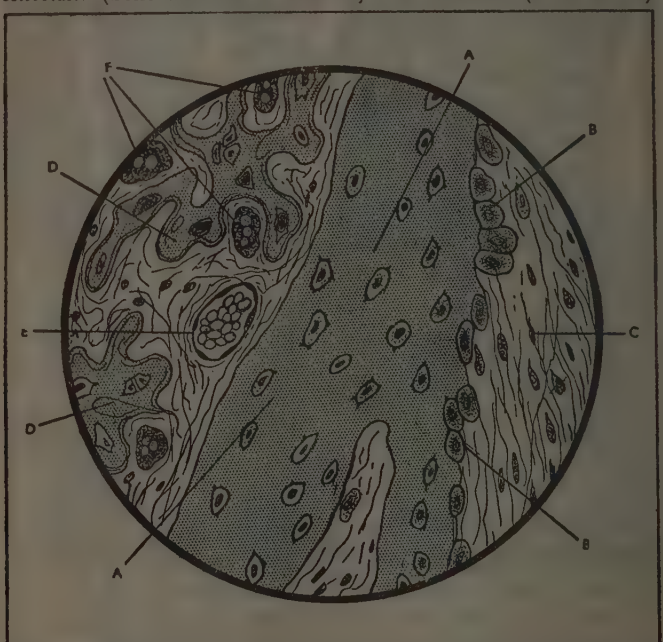


Fig. 9. *A small piece of bone in process of growth.* (a) *Firm bone.* (b) *Bone builder* (*osteoblast*). (c) *Fibrous tissue cells.* (d) *Calcified material.* (e) *Blood vessels.* (f) *Bone eater* (*osteoclast*).

The osteoclasts destroy all old bone and cartilage—not haphazardly, but just in those places where osteoblasts can lay down new perfect bone. Working hand in hand like this, the osteoclasts hollow out a cavity, where the " marrow " will be placed, whilst osteoblasts build up bone, creating the Haversian systems around the hollowed out Haversian canals. It is a masterpiece of co-operation. Apart from this process going on within the bone, the periosteum (the

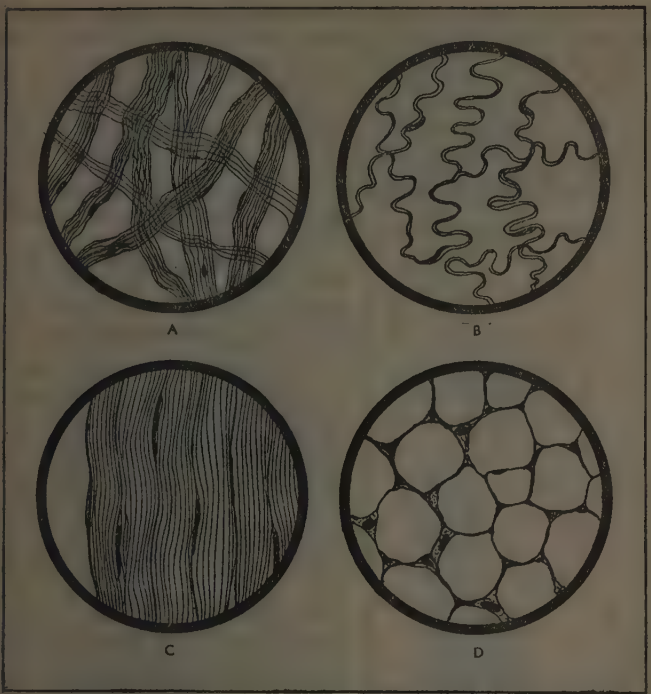


Fig. 10. *Microscopic view of four types of tissue which serve to protect the body.* (a) *White tissue from membranes.* (b) *Elastic fibrous tissue.* (c) *Tendon tissue.* (d) *Fat.*

fibrous sheath around the bone) is also supplying myriads of osteoblasts, which build in such a way that the bone grows in thickness.

This fibrous tissue of which periosteum is a specialized example is perhaps the commonest tissue of the body. The " connective " tissues of the body (some of which are shown in Fig. 10) have the function of binding tissues together. For this purpose there are several kinds. Fibrous tissue of white and yellow elastic types (A and B) is the simplest. The cell is modified so that the small nucleus is almost obscured by wavy bands of fibres, which are immensely tough and strong (C). It is from this kind of tissue

that the tendons at the ends of muscles, ligaments round joints—all places where strength is essential—are composed. Often bone itself will break whilst the fibrous tissue remains firm.

Another connective tissue is fat (Fig. 10, D), where the cell is in this case modified to contain a large fat globule. A layer of fat is found almost everywhere in the body, particularly under the skin, where it helps keep in bodily heat. There is also a very large amount inside the belly, or abdomen, and the size of the buttock is mostly due to the fact that it is one of the most important depots for the storage of fat in the human body.

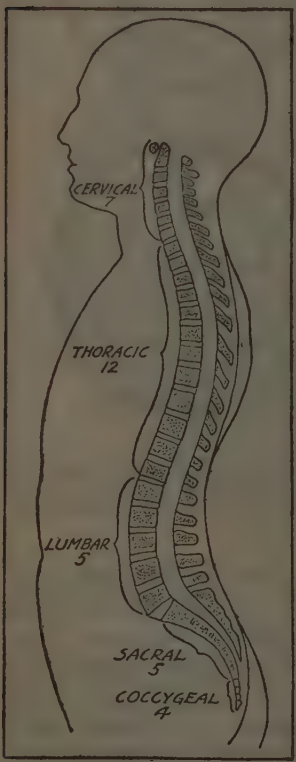


Fig. 11. *The shape of the spine and its chief bones.*

Having now seen what bone and flesh really are, we can next describe how these tissues are built into the complex structure of the human body.

The skeleton (illustration seen on page 6) consists of the bones and cartilage of the body. It can be divided into two main parts, one of which contains all the bones that go to form the axis of the body—the head and trunk. These bones really form the body proper. The group, consisting of the limbs, is really a series of additions, whose main use is for transporting the body from place to place. Man, standing on his hind legs, and using his hands for skilled work, is the first big evolutionary modification of this ruling design, although, of course, a few other animals also stand on their hind legs.

Bones, therefore, bear weight, act as levers, shape the body, and protect delicate organs such as the brain from injury.

The skeleton consists of two hundred and six bones of different shapes and sizes—some long, some flat, some short. Long bones usually function as levers (look at the elbow and arm bones); short bones, especially in groups, confer strength, as in the wrist; flat bones,

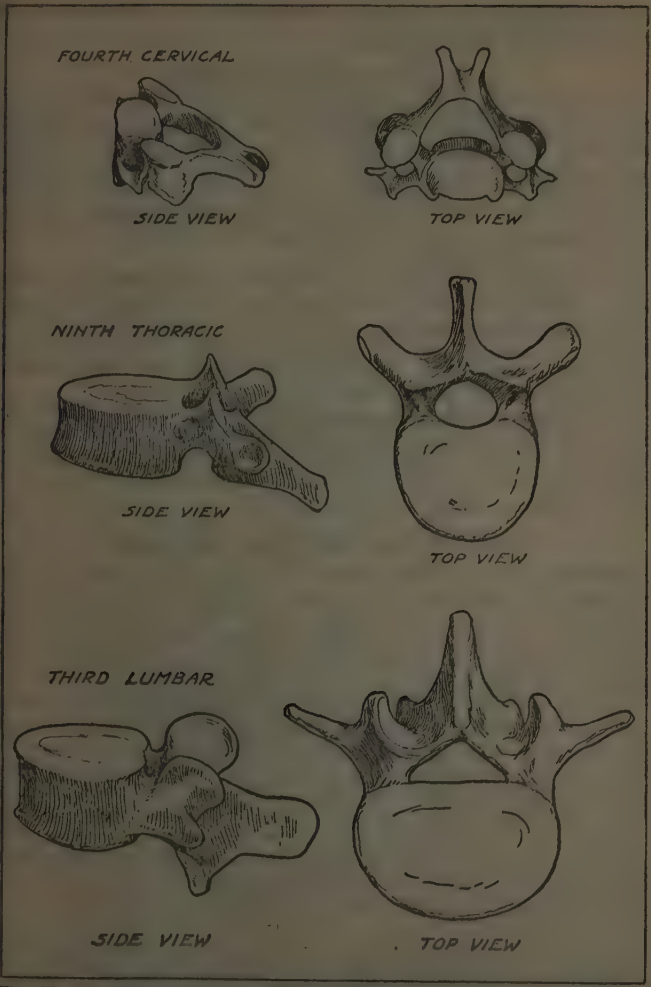


Fig. 12. Various types of vertebræ. There are thirty-three vertebræ in the spinal column differing slightly according to the positions they occupy.

such as the shoulder-blade, give attachment to muscles or act as armour plating, as in the skull.

THE BASIS OF THE SKELETON

The basis of the whole skeleton is the vertebral column (Fig. 11). Not only has this column to support the weight of the trunk of the body, but it must be mobile—free to move from side to side, and backwards and forwards. For this reason it cannot consist of one long straight bone, but is divided up into many small bones called vertebræ. The third great purpose of the vertebral column is the protection of the delicate spinal cord which runs down in the hollow tube inside the bones.

Each vertebra consists of a knobbly ring of bone round a central space. These rings all fit on to one another so that the spaces form a continuous smooth-lined canal. Between each vertebra there is, of course, a layer of articular cartilage, as there always is where joints are formed. In this way the strong and supple central pillar of the body is built up.

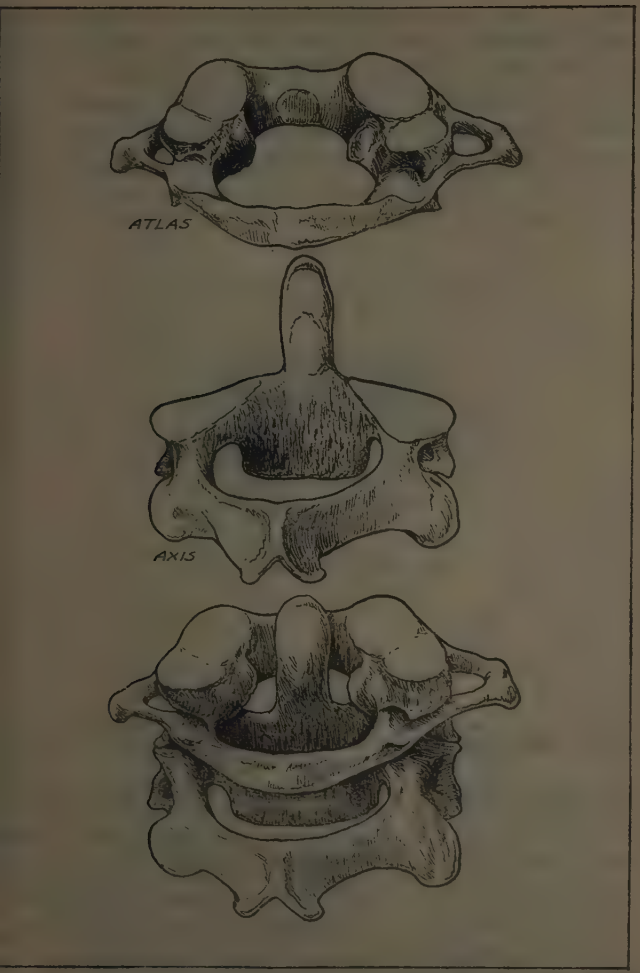
But let us examine a vertebra more closely. In Fig. 12 you see three typical vertebræ. There is, in front of the central hole, or *foramen*, a solid rounded buttress of bone—the body of the vertebra. This is the part that carries the weight from the vertebra above to the one below, and so must be solid.

HOW THE VERTEBRÆ ARE ARRANGED

Through the vertebral foramen runs the spinal cord, carefully wrapped in its enclosing membranes, the *meninges* (pron. : menn′-in--jeez). At the sides of this foramen, two fingers of bone jut out on each side, known as transverse processes. Behind projects the "spinous process." It is the tips of these spinous processes which you feel when you run your finger down your back.

At the base of the transverse processes there are two flat plates, one on each side of the vertebral foramen. These articulate with the next-door vertebræ and beside them, run out the nerves of the spinal cord. On the body of the thoracic vertebra, just in front of the central foramen, there is another pair of these plates or facets, seen better in the side view (Fig. 12). This is where the ribs are attached. As they sweep round and outwards, they also make a joint facet on the tip of the transverse process. Each rib articulates with two vertebræ, leaving two pairs of marks on each.

Each of the thirty-three vertebræ of the spinal column is modelled on this pattern. But in the various regions, there have developed certain differences from the type due to their particular function. For instance, the spinal column is divided into *cervical* (neck) (pron. : ser′-vikel), *thoracic* (pron. : thor′-assik), *lumbar*, *sacral* and *coccygeal* (pron. : koksy-jeel) regions, and each have their own characteristics.



ig. 13. *The atlas and the axis. On these two bones depend the movements of the head. They are shown here separately and interlocked.*

The cervical or neck vertebræ (Fig. 12) are the smallest of those that are movable. They are lightly built and at each side there is a special hole or foramen, through which the vertebral artery which helps supply the brain, winds its tortuous course. On the first cervical vertebra rests the skull, for which specially strong articular facets are prepared. For this reason this vertebra has been well named the *atlas*, for surely all the cares of the world are borne by its shoulders. This vertebra has also lost its body, which has become attached to the vertebra below, as seen in Fig. 13.

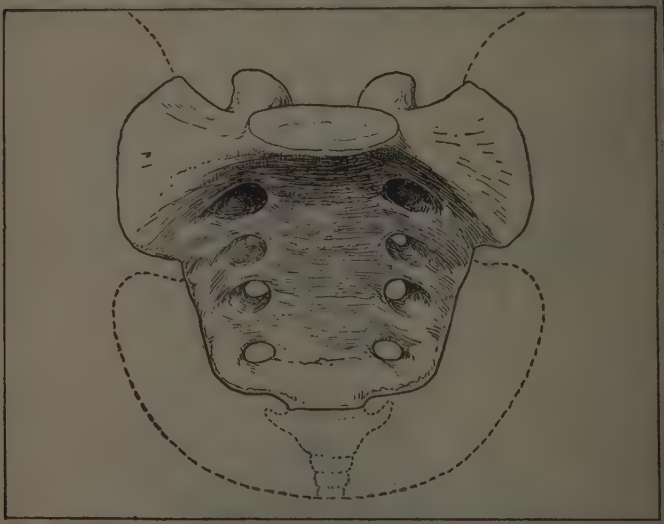


Fig. 14. *The wedge-shaped sacrum* (*the base of the spine*) *lying between the hip-bones, shown by the dotted lines.*

This strange modification of these two vertebræ has a purpose. The atlas is fashioned so that free nodding movements of the head can be performed; the axis, or second cervical, so that the head can be turned from side to side round this axial peg, while both are fashioned to ensure that the head shall be freely movable.

The twelve thoracic or chest vertebræ we have already described as one type—they all have special facets for articulating ribs.

The lumbar vertebræ (Fig. 12) are five in number; they are the largest of all. Their broad large bodies show that they are specialized for bearing the whole weight of the upper part of the column. The *sacrum* (Fig. 14) is a large bone formed from the

fusion of five vertebræ. Shaped like a curved triangle, it fits in like a wedge between the two hip-bones—an ideal mechanism for transmitting the weight to these parts. Four round holes through which nerves penetrate, divide this bone into its five primitive parts. The sacrum is a bone which shows marked sexual differences. In women it is short and broad, slopes backwards and is but slightly curved. In men it is longer, more evenly curved and not directed so sharply backwards.

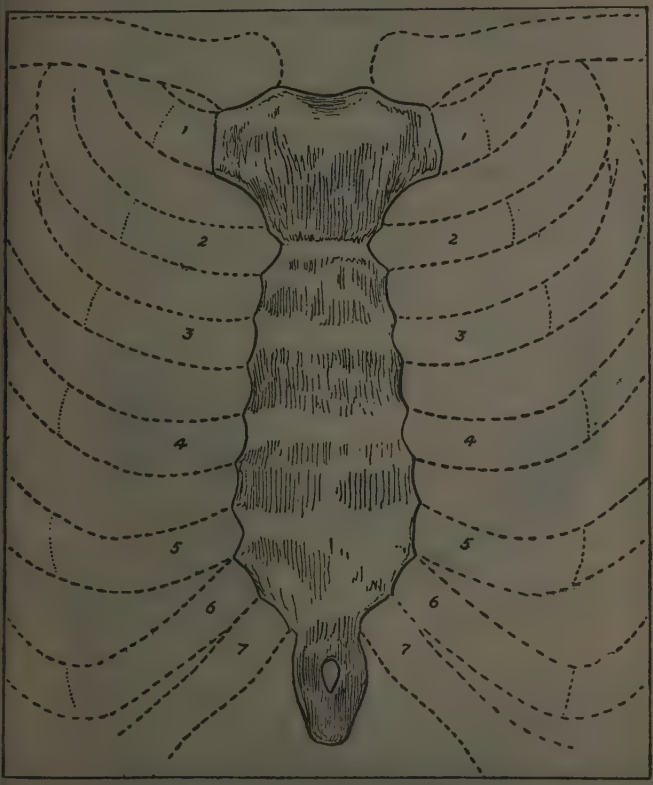


Fig. 15. *The breast-bone or sternum, shown in relation to the ribs and collar-bones (dotted lines).*

Lastly, the *coccyx*, the rudimentary tail of man, consists of three or four small vertebræ—barely recognizable as such—fused together. The drawing (Fig. 11) shows how, in the body, the vertebral column takes on various curves. The original forward curve is produced by the fœtus lying round and bent up in the womb. The opposite curves in the neck (cervical) and lumbar regions are developed later when the infant begins to sit and stand upright.

In the region of the chest, each vertebra, as we saw, supports a rib, which sweeps round in a curve to the midline in front, where it joins the breast-bone or *sternum*, as seen in Fig. 15.

There are twelve ribs usually, and in spite of the story in Genesis, according to which, God made woman from one of Adam's ribs, there are the same number in both sexes! Occasionally, however,

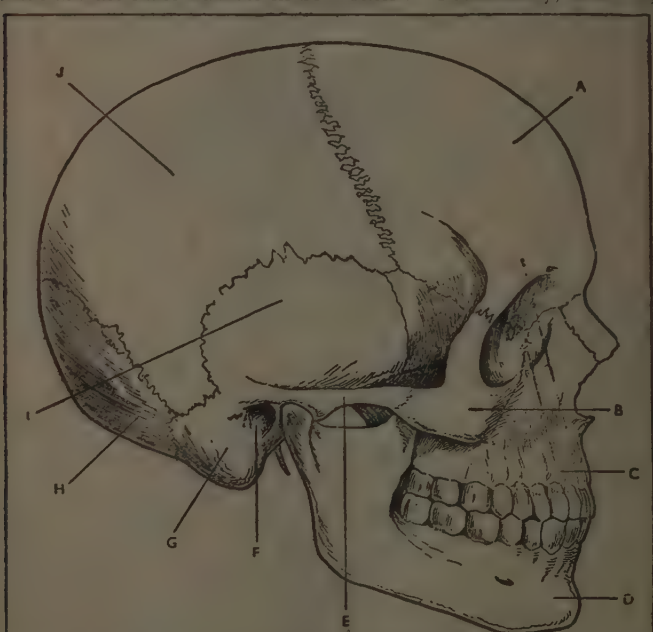


Fig. 16. *A side view of a typical human skull, showing the various bones of which it is composed. Their technical names are as follows*: (a) *Frontal;* (b) *zygomatic;* (c) *maxilla;* (d) *mandible;* (e) *zygomatic process;* (f) *auditory meatus;* (g) *mastoid process;* (h) *occipital;* (i) *temporal;* (j) *parietal.*

there may be small ribs attached to the last cervical vertebra or to the first lumbar. Cervical ribs, when they are present, often cause pain in the arm, and even wasting of the muscles of the hand, by their pressure on the nerves to the arm. The first seven ribs are known as "true" ribs because they join the sternum in front. The other five are known as "false" ribs. In the illustration on page 6 these are seen to curve upwards in front, forming the cartilage of the rib above, except for the eleventh and twelfth whose ends are quite free—so being named "floating" ribs.

The main function of ribs is to protect the vital heart and lungs within, and by their movement, to aid in the act of breathing. This we shall describe later.

THE STRUCTURE OF THE BREAST-BONE

The sternum, or breast-bone (Fig. 15), is flat and shaped like a short blunt sword, with the handle uppermost. The point of the sword you can feel for yourself in the angle where the ribs meet in front, at the very top of the belly wall. If you feel down the front of the sternum, opposite the second rib you will detect a ridge. This is where the handle (or *manubrium*) joins the body of the bone. It is an important point to anatomists, and is named the Angle of Louis, after a French surgeon of the eighteenth century, Antoine Louis. As a whole, thoracic vertebræ, ribs and sternum form the thoracic cage, which opens at the top into the neck, and below is divided off by the *diaphragm* (pron. : di'-a-framm) or *midriff*, from the *abdomen*. This space is entirely shut off from the atmosphere, and it is this fact that enables the lungs to expand inside it and take in air. But of this too, more later.

Women's chests are smaller than men's and the upper ribs are more movable, which accounts for the "heaving bosom" of the damsel in distress. Men's chests simply cannot "heave" much.

THE SKULL AND ITS BONES

Of the twenty-two bones of the skull (Figs. 16, 17 and 18)—certainly the most complex part of the human skeleton—we have not sufficient space for individual description. The skull includes two differently used parts, of which the more important is that used as a brain case. This is the *cranium*. In front of and below this is a bony mass which forms the face.

The atlas (or first cervical vertebra) articulates with the occipital bone of the skull (Fig. 18) which you feel if you run your finger up the back of the neck until it comes to a knobbly bump on the back of the skull, just concealed by the hair in man. This knob is made by the pull of muscles, and so is larger in men than women. A big hole (the foramen magnum) in this bone (the occipital), is occupied by the spinal cord as it passes from brain case to spine.

The sides and roof of the skull are formed by two flat plates the *parietal* bones (Fig. 16) and the forehead by the *frontal* bone, which also forms the roofs of the eyeballs and the nose. The "temple" is formed on each side by the *temporal* bone, which

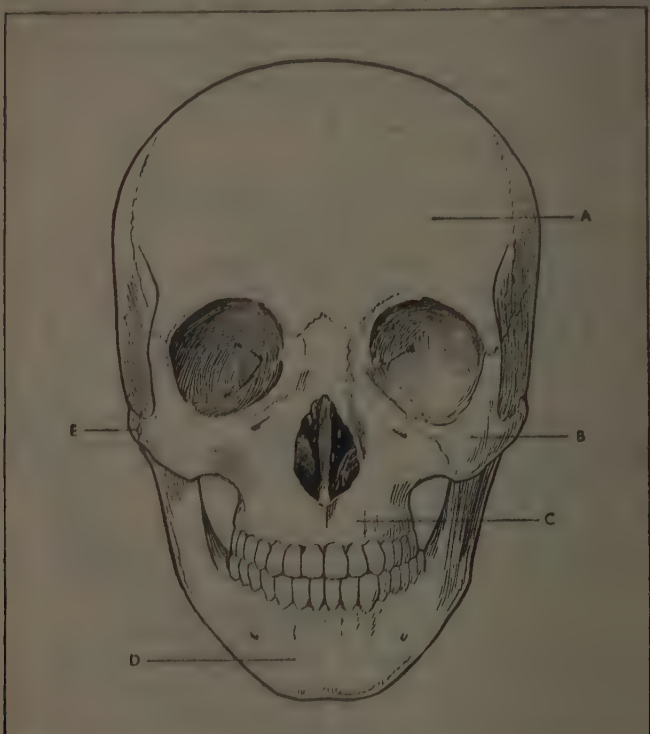


Fig. 17. *A front view of the skull.* (*For lettering, see Fig.* 16.)

lower down, contains the whole marvellous structure of the ear. Running forward from the ear, you can feel a bar of bone that blends with the cheek. This is the *zygomatic* process, and if you clench your teeth, you will feel that the *masseter*, the muscle of mastication and chewing, is attached to this bar of bone, which runs into the zygomatic or cheek-bone proper.

In the face, the space between lower border of eye socket and the corner of the lip is occupied by the *maxillæ*—which form the whole of the upper jaw. In these bones are all the sockets of the upper teeth, and meeting in the middle they form part of the roof of the mouth (seen clearly in Fig. 18).

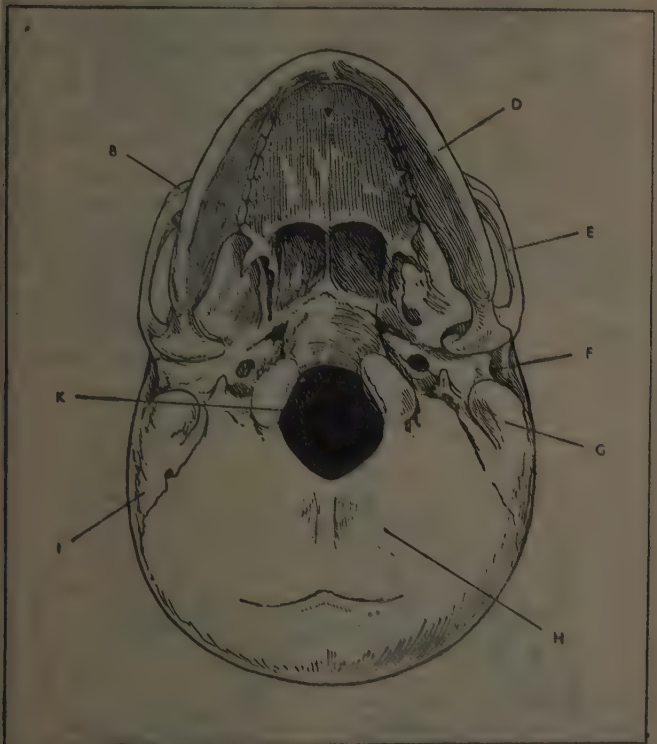


Fig. 18. *The skull from below, showing the point* (k) *at which it is attached to the spine.* (*For lettering, see Fig.* 16.)

The longest and strongest bone, however, in the whole face is the *mandible*, or lower jaw. You can feel this bone with your finger, first forming the bony chin, then running backwards to articulate in front of the ear under the zygomatic bar. It is covered by

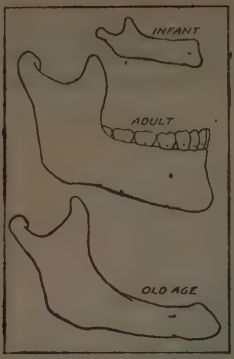


Fig. 19. *How the shape of the jaw alters from infancy to old age.*

the powerful masseter muscle in this upper part. The inside of this bone is full of remnants of the old gill-arch, and the delicate bones of the ear are actually developed from bones which originally formed part of the lower jaws of primitive animals. Age changes the shape of the mandible to a degree, so that the toothless jaw of old age is astonishingly like the toothless jaw of infancy (Fig. 19). In many ways, even anatomically, the term " second childhood " is a true description of our declining years !

The skull at birth (Fig. 20) is very different from that of adult years. In the new-born babe, the cranium or brain case is much larger in proportion to the rest of the body than in a grown-up, and the face is smaller. There are also spaces known as *fontanelles*. The anterior fontanelle is in the midline where frontal and parietal bones meet.

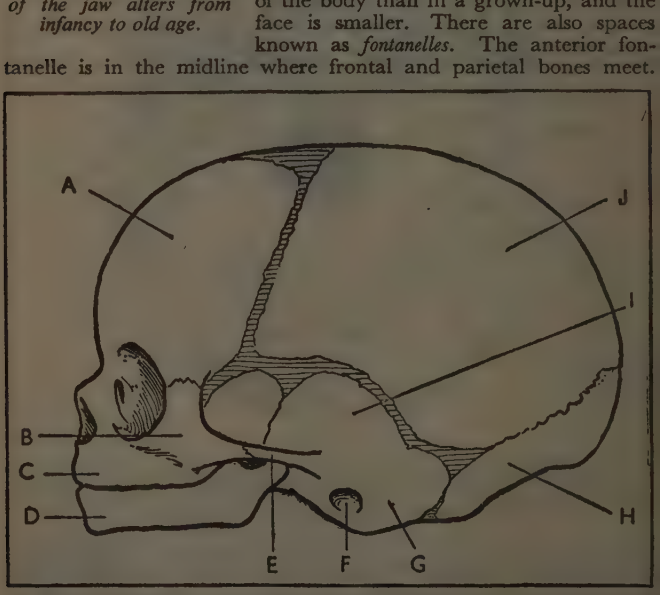


Fig. 20. *The skull of a newly born infant, showing how loosely the bones are knit together.* (*For lettering, see Fig.* 16.)

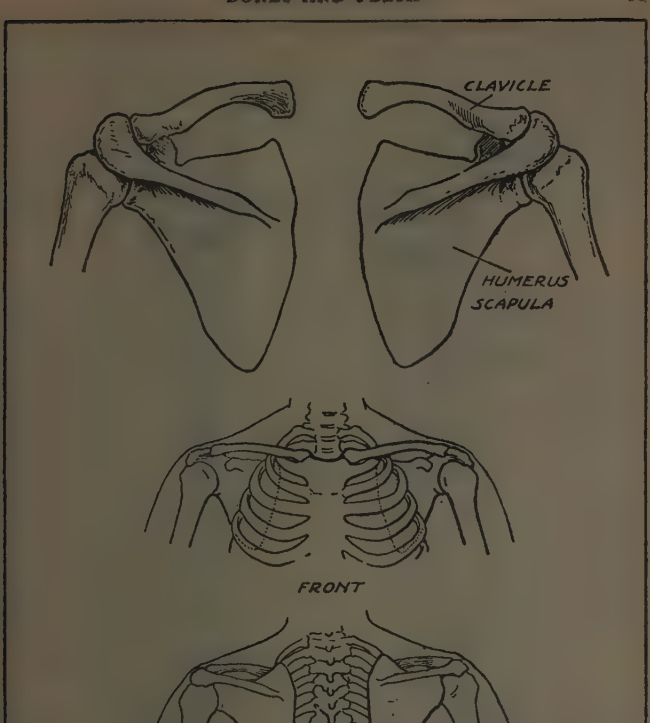


Fig. 21. *The bones of the shoulder and how they fit on to the chest.*

Here there is no bone between the outside and large veins that run over the surface of the brain. This forms an ideal place for running in fluid or even blood into a baby, perhaps desperately ill for lack of it. When puberty comes, the female skull retains more of the child-like characteristics. It is smaller, the teeth and jaws are more delicate, the face more rounded.

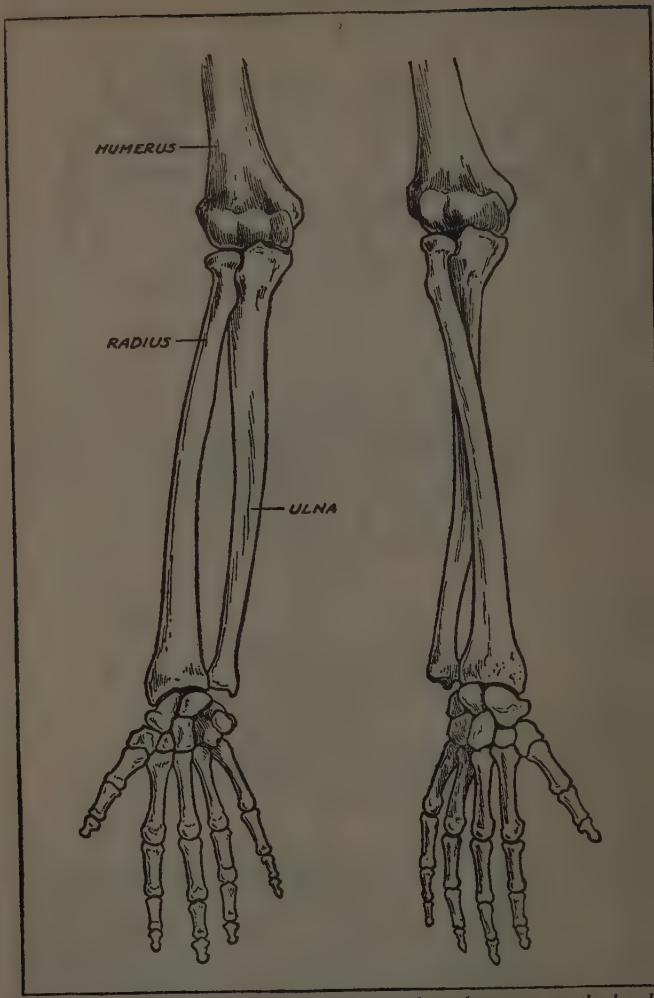


Fig. 22. The bones of the forearm, showing how they move as the hand is turned.

The bones of the arm are of two kinds—those in the arm itself, nd those which attach the arm to the body. Of these the shoulder-lade or *scapula* is the best example (Fig. 21). This flat bony late forms a centre for muscles, from which they can pull—on ibs, spine, or arm—in fact in almost all the directions of the com-ass, so that the scapula is, on the whole, kept in the right position y a balanced pull from all sides. If you put your right hand under our left arm and as far round your back as you can, and then aise your left arm up and down, you will feel the scapula rotating s the arm is elevated.

THE FRAGILE COLLAR-BONE

The collar-bone or *clavicle*, forms with the scapula, the shoulder irdle whereby the arm is attached to the body. This bone (also een in Fig. 21) has unenviable fame from the fact that it is so easily roken. It is a thin, rounded bar which runs from the top of the reast-bone, where you can feel its edge at the side of the central ollow of the root of the neck, to articulate with the scapula and orm the point of the shoulder. Its purpose is to enable one to aise the arm sideways. For this reason it is not present in animals ike horses whose forelegs are used for progression only.

The upper arm is formed by a single long bone—the *humerus*, vhich runs from shoulder-joint to elbow. Around the bone are vrapped layers of muscles. Round the inner edge of the lower nd at the elbow, a nerve—the *ulnar*, which supplies the little inger—runs in a sharp bend, so that if you knock this part a stab f pain shoots down to the little finger side of the hand. We com-nonly describe this as hitting " the funny bone "—an expression resumably describing the lower end of the humerus !

THE BONES OF THE FOREARM

Below the elbow the arm consists of *radius* and *ulna*—two bones hat run side by side to the wrist. The hand is attached almost ntirely to the large end of the radius at the wrist (Fig. 22) and vhen the hand is turned from palm upwards to palm downwards—r pronated—the radius rotates round the ulna. Muscles for many f the movements of wrist and fingers rise from these two bones—nd, if you feel the front of your arm whilst you clench your fist, ou will find the tendons tighten like thongs.

The human hand is composed of eight small wrist-bones and ineteen small rod-shaped *metacarpal* bones and *phalanges*—these atter forming the three parts of each finger except the thumb, vhich has two only. The knuckles are the ends of the metacarpal ones. As we mentioned before, the human hand is arranged on beautiful and yet primitive pattern, which enables it to accomplish great variety of tasks.

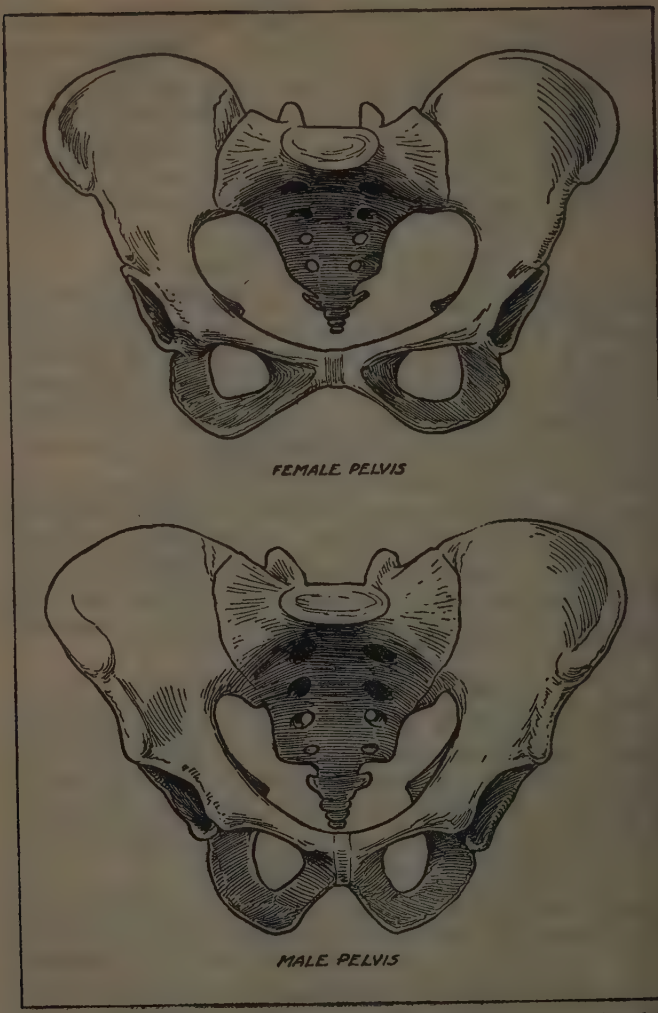


Fig. 23. *The difference in structure between the female and the male pelvis.*

The complicated hip-bone (Fig. 23) forms a girdle round the body to which the legs are attached. The upper edge of the flat plated *ilium* can be felt on each side. Below these the thigh-bones (*femora*) articulate in a firm ball and socket joint—the *acetabulum* (pron. : as-see-tab'-ulum). Here the pubic bone meets its fellow in the midline in the *genitalia* (pron. : jee-ny-taylia). The hip-bones carry the weight from wedge-shaped sacrum to thigh-bones. Along the main line of weight-bearing stress, there is accordingly a rounded buttress of bone which forms the brim of a basin containing the bladder and female genitalia—this basin is the true pelvis. In view of the different functions of the pelvis in male and female, the bony shape is considerably different as seen in Fig. 23. The female pelvis is shallower; the sacrum, as we have noted, slopes

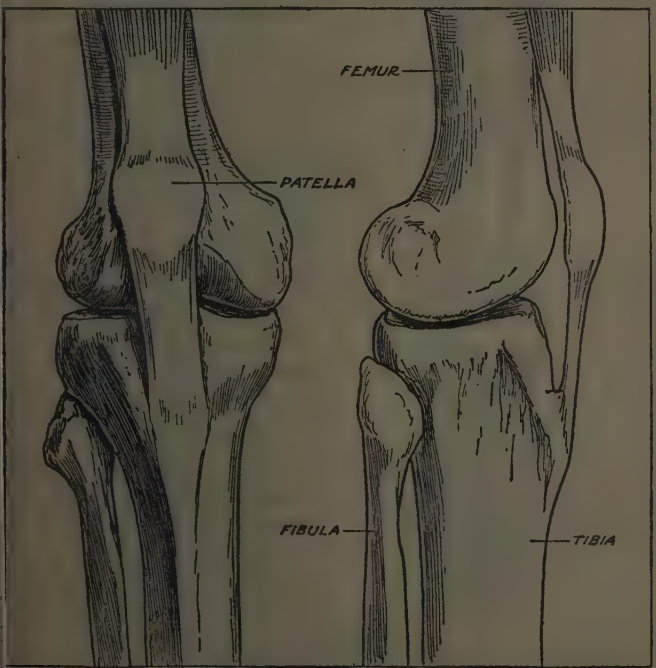


Fig. 24. *A front and side view of the bones of the knee, showing how the knee-cap, or patella, links the thigh and the shin.*

Fig. 25. The bones of the lower leg, the ankle and the foot.

more obliquely and is shorter and wider; the whole of the basin is less massive and less marked by muscles than the male pelvis. These differences in shape appear as early as the fourth month of fœtal life within the uterus.

The *femur*, or thigh-bone, is the strongest and longest of the body. The rounded head of the bone lies snugly in the cup of the acetabulum, which fits round the neck of the bone. The protuberance which you can feel if you follow up the outer side of your leg, is the greater *trochanter* (pron.: tro'k-anter) to which many muscles are attached. The long shaft of the bone is wrapped in layers of powerful muscles acting on the hip- and knee-joints.

At its lower end the femur articulates with the *patella*, or knee-cap, and *tibia*, thus forming the knee-joint (Fig. 24). The patella is a curious bone which lies in the tendon of attachment of the great mass of muscles on the front of the thigh. These collect into a flattened ropy tendon, which is carried over the knee-joint by the round patella and goes on to attach itself to the upper end of the leg-bone or tibia below. This is the tendon which, if struck sharply, causes a contraction of the muscle so producing the "knee-jerk"—a test of great significance to doctors. Cross your legs, let the foot hang loosely and with the edge of a book or a ruler strike sharply just below the knee-cap. Does it jerk?

The tibia and *fibula* run side by side (Fig. 25) and correspond

exactly to the radius and ulna of the arm. Like the other two, these long rods of bone serve for the attachment of muscles, only in this case they must be sturdier on account of having to bear the weight of the body. The ankle is formed where the tibia, fibula and foot meet. The projection on the outer side is the end of the fibula, the less marked one on the inner side is the tibial end.

THE STRUCTURE OF THE FOOT

The foot is as complex, and on exactly the same pattern as the hand (Fig. 26). A bunch of small bones—the *tarsus*, joins on to rod-shaped bones, *metatarsi*, and phalanges. The weight of the body is borne on these bones, which are therefore firmer and less movable than those of the hands—compare the great toe and the thumb, for example. Tendons and ligaments tie up the bones into a long arch running from heel to toe. It is when these weaken that the pain of "flat-foot" develops. The anatomical result is clearly shown in Fig. 26.

The stiff, hard skeleton is brought to movement and life by the muscles which run from bone to bone. The fixed point from which the muscle arises is known as its "origin"—the movable point which is acted upon its "insertion." Between these points is the rounded, fleshy "belly" of the muscle, attached at each end to the periosteum of the bone by tendons.

THE NATURE OF MUSCLE

This is the usual pattern of muscle shape, but there is variation, i.e., the muscles that line the abdomen are in flat sheets.

Seen under the microscope, muscle is of two types (Fig. 27) striped or "voluntary," and smooth or "involuntary." The former is the type we are dealing with in the skeleton.

The great function of a muscle is to contract. This means that the two ends are brought closer together, and the belly of the muscle consequently broadens. This contraction is brought about by a stimulus which usually reaches the muscle by the nerve supplying it—though it can respond to an electric shock or injury, even when this nerve has died. Muscular movement as we know it, is sustained over a period of at least one or two seconds. To maintain this, the muscle has to keep on contracting very rapidly—for each individual contraction lasts only about one-tenth of a second. You can work out how many contractions are necessary to hold a pail of water in your hand for a minute! But this fusion of single contractions is the body's method of meeting that difficulty. It is known as healthy muscle tetanus. In the disease known by that name abnormal impulses keep on passing up the muscles, especially the masseter of the jaw, so that it cannot relax, and "lockjaw" results.

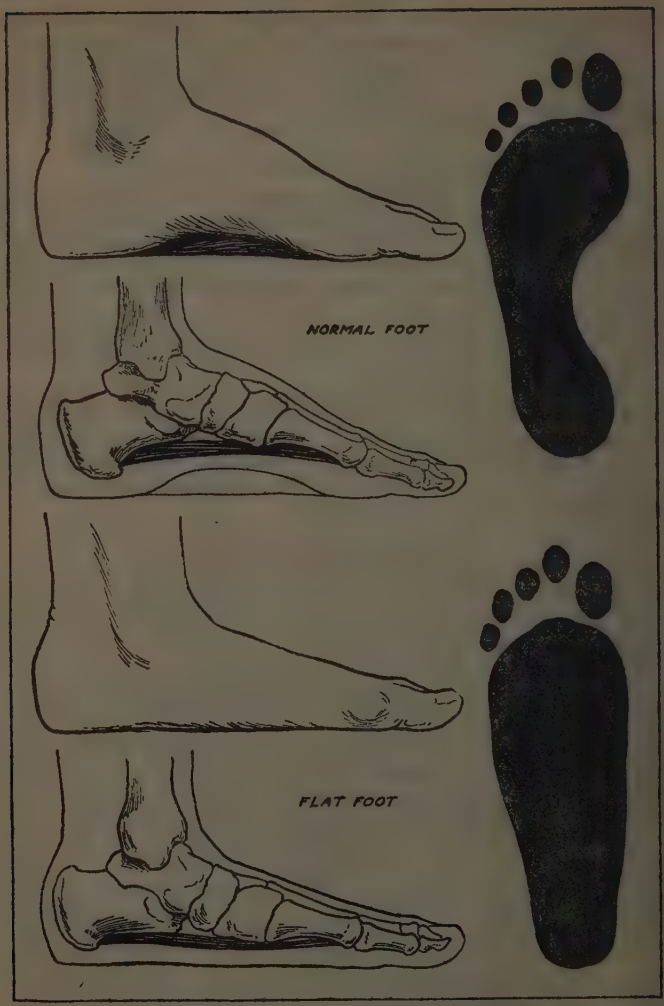


Fig. 26. *A normal and a flat foot, showing their respective imprints.*

When a muscle contracts, energy is liberated, both in the form of work and heat. The work done in lifting a weight is obvious. The heat created sends up the temperature of the body and thereby sets going the cooling mechanisms such as sweating. Further, when we are cold we "shiver." This consists of small movements of the muscles, which are doing no work this time but burning fuel for the supply of warmth, so raising the temperature of the body back to normal.

What exactly the fuel is composed of is still a matter of argument, but it appears that sugar in some form is burnt up in oxygen, so releasing energy, and that lactic acid (the acid of sour milk), and carbon dioxide are produced. If an excess of lactic acid is produced, and cannot be removed by the blood, then the muscle becomes "stiff"—as all of us must have felt some time or another after hard exercise.

You see in Fig. 28 how different the human skeleton looks when it is clothed in the writhing grace of its muscles. We cannot try here to make anything like a complete description of all these muscles, which all work on the same principle, so we shall select those which are, for various reasons, of especial interest and importance.

The muscles of the human face rank first, perhaps, under both

Fig. 27. Sections of muscle as seen under the microscope and enlarged five hundred times. (Left) *Involuntary muscle.* (Right) *Voluntary muscle.*

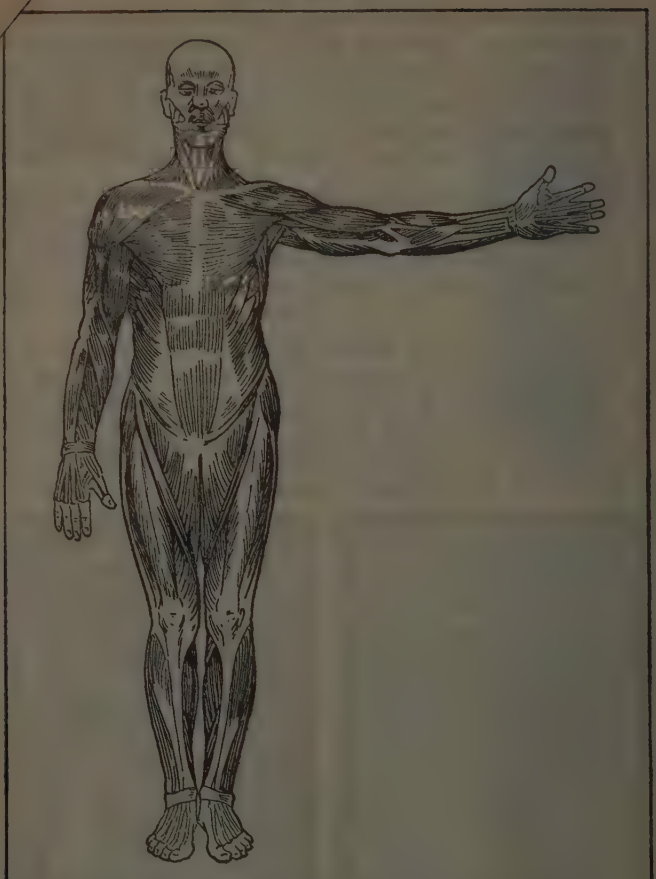


Fig. 28. *The human skeleton when clothed in its muscles.*

headings. For, being responsible for expression and a large part of speech, where should we have been without them?

You see in Fig. 29 how, round the eye (A) and the mouth (B) are circular rings of muscle. In each case, when these contract

they close the orifice concerned, whether it be eye or mouth. When *orbicularis oculi* (A) (the eye-ring) is gently put into action the eyelids blink, firmer contraction draws down the forehead, and produces those wrinkles radiating from the corners of the eyes known as "crow's feet," creases of such importance to beauty specialists.

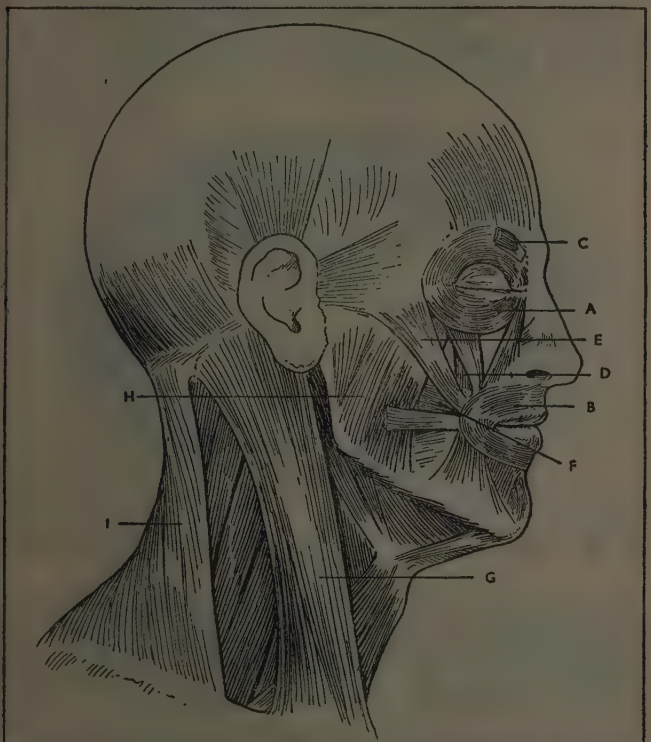


Fig. 29. *The muscles that express emotions.* (*For lettering, see text.*)

Between these two rings of muscle, you notice many small straps radiating as it were in all directions from the corner of the mouth. One goes up alongside the nose, another to the cheek-bone, a third runs straight back into the tissue over the powerful masseter muscle (H), a fifth and sixth pass downwards to the chin region.

Notice also one small muscle which, rising from the root of the nose runs outwards to be inserted into skin above the middle of the eyebrows. When this—the corrugator muscle (C)—contracts, the vertical furrows of suffering and pain appear in the skin of the forehead.

The strips of muscle round the mouth all create expressions on the face. *Caninus* (pron. : kan'-eenus) (D), draws up the lip in a sneer. Its neighbour—*zygomaticus* (E)—by widening the mouth

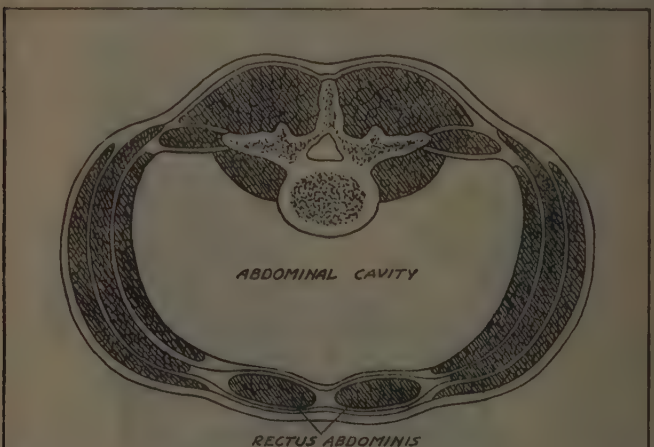


Fig. 30. *Transverse section of the abdominal cavity, showing the chief layers of muscle.*

produces a smile. That running down into the chin wrinkles the chin and pouts out the lower lip in an expression of doubt. The infinite number of combinations that can be made with all these muscles give rise to that enormous variety of facial expressions, in which human beings excel all other animals.

THE TONGUE

In the mouth lies the tongue—a muscle which perhaps exceeds all others in the subtlety of its action, for by it sound created in the voice-box is cut and clipped until it takes the shape of a word. But running between the upper and lower jaws on each side is a muscle which forms the fleshy part of the front of the cheek, known as the *buccinator* (F) (pron. : buk-sin-aytor). It is muscle for blowing or whistling. And it is the art of using this muscle

that makes all the difference between a clarion call and the peculiarly dismal croak, known to all would-be buglers.

The neck consists almost entirely of muscles attached to the vertebræ with the gullet (*œsophagus*) and windpipe (*trachea*), passing down in front. The great blood vessels to the brain—the *carotid arteries* run up on each side.

Running from the mastoid process behind the ear, down to the inner end of the clavicle is the *sterno-mastoid* muscle (G). It is the tendon of this that stands out in front of the neck on turning the head to one side. This muscle with its fellow shakes the head expressing "no."

This muscle is sometimes injured in child-birth and becomes contracted and scarred, so giving rise to "wry-neck."

THE COMPLEX MUSCLES OF THE BACK

The deep muscles of the back, from neck to sacrum are of great variety and complexity, forming a source of trouble and irritation to medical students who have to learn them. But the plan of them is such that every kind of movement can be performed between one region of the spinal column and another. These muscles more than any others retain signs of the original segmentation of the body—each segment corresponding to a vertebra—and this adds to their complexity.

The muscles of the thoracic cage are mainly the *intercostals* which run from rib to rib. These and the muscular diaphragm, which partitions off the thorax from the abdomen, will be described in more detail in a later chapter on respiration.

The abdomen is the cavity which contains many of the vital organs of the body. In view of this it is rather surprisingly poorly protected. There are no bony structures such as ribs, to protect these delicate parts of the body.

MUSCULAR PROTECTION OF THE ABDOMEN

Behind there is the backbone, at the sides and front muscles have to take on this protective duty (Fig. 30). For this purpose there are three thick muscular sheets which run round each side from the loins, and join up with a long band of muscle the *rectus abdominis* which runs from the ribs above to the pubic bone below. These muscles can compress the contents of the abdomen as in expelling urine from the bladder, when their compressing action is increased by the diaphragm pressing downwards from above. They also perform the act of vomiting, and aid in the expulsion of the fœtus from the uterus in child-birth.

Owing to the peculiar development of the testicle, there is sometimes a weakness in the lower part of the muscle sheet in the groins. It is this part which is the site of protrusion of the lining membrane

Fig. 31. *Muscles of the lower part of the abdomen, showing a typical hernia or rupture.*

of the abdominal cavity—the *peritoneum* (pron. : perry-ton-ium), so forming the *hernia*, a swelling of the duct, shown in Fig. 31.

The bottom of the abdominal cavity is formed by the pelvis. If we look at the skeleton, we shall see that there is no bony plate completing the basin. This is provided by a stretch of muscle, through which pass the end of the gut—the rectum, the genital tube, and the urinary tube or *urethra* (Fig. 32). This sheet is called *levator ani* and its main functions are to support the pelvic *viscera* and to constrict the rectum.

HOW WE SHRUG OUR SHOULDERS

Arising from the spines of all the vertebræ of the thoracic region (Fig. 33) is a muscle shaped like a monk's cowl and known as the *trapezius*. All its fibres collect and run into the shoulder-blade, being inserted on a special ridge, and into the outer part of the collar-bone. In a way this huge sheet of muscle should be added to those of expression, for it is responsible for shrugging the shoulders. One wonders whether Frenchmen have it very well developed ! It also braces back the shoulders.

Next to it is a similar sheet, the *latissimus dorsi*, which winds across the lower end of the shoulder-blade and ends by being inserted into the upper end of the humerus. As it does so it forms the back wall of the arm-pit which can easily be felt. When this muscle acts it draws down the arm sharply. It is the muscle of the lumber-jack—if he still uses an axe to fell trees.

The front of the chest is covered by *pectoral* muscles, in sheets (Fig. 34). The largest of these collects its fibres together, just like *latissimus dorsi*, and running back forms the front wall of the armpit, being inserted into the humerus, alongside the latter. The rounding of the human shoulder, one of the beauties of the human body, is due to a muscle, the *deltoid* which, rising from the clavicle and ridge on the shoulder-blade, sweeps over the upper end of the

Fig. 32. *The muscular floor of the pelvis.*

humerus to be inserted midway down it (Figs. 33 and 34). Sometimes this muscle wastes in disease and the beauty of the rounded shoulder disappears.

STRUCTURE OF THE BICEPS

The biceps of the arm is perhaps the best known muscle of the body. Few have not shown their strength by bending up their arms to make it "swell." Prize-fighters are very fond of having their pictures taken in this position to make a muscular impression. It is called "biceps" because it has two heads, one coming from the shoulder-joint, one from the front of the shoulder-blade (Fig. 35).

Behind the arm is the triceps—three-headed—which antagonizes its opposite the biceps, and straightens the arm. Both these muscles act on the forearm.

In the forearm arise the muscles for moving the wrist and fingers. Corresponding with the complexity of these movements, there are many groups of muscles. Those which bend or flex the fingers rise near the elbow in front. Their fleshy bellies give way to long

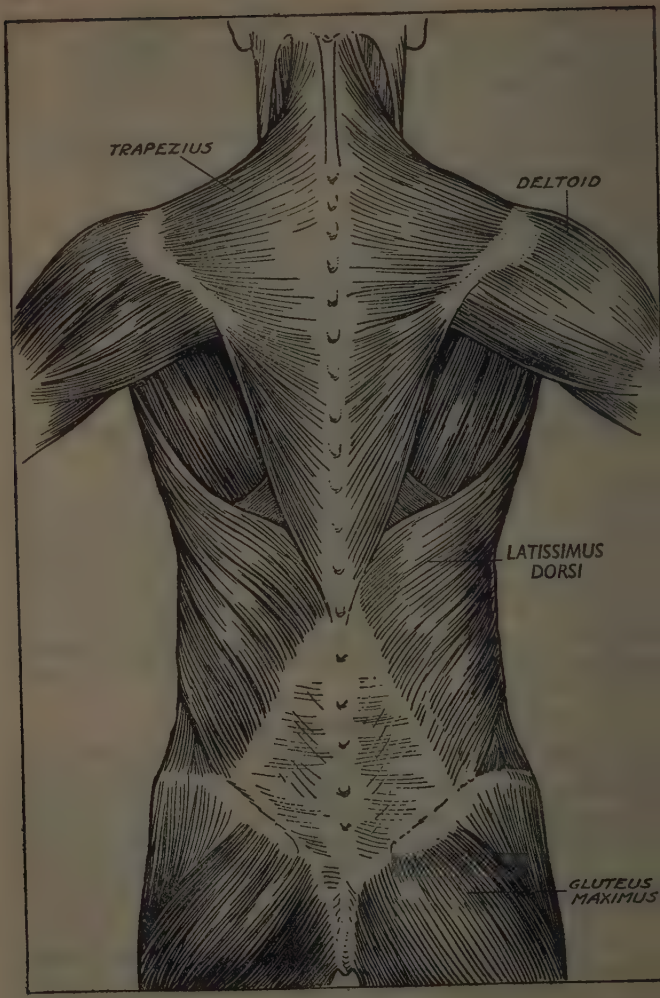


Fig. 33. *Arrangement of the chief muscles in the shoulders and back.*

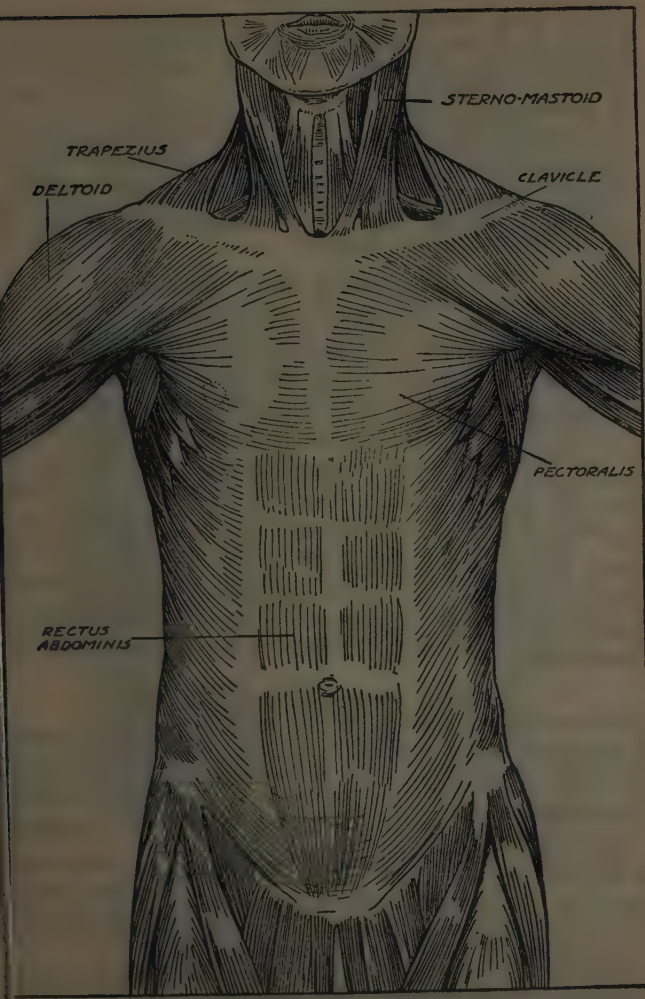


Fig. 34. *Arrangement of the chief muscles of the chest and abdomen.*

rounded thongs of tendons, which pass through specially lubricated channels in the wrist and fingers to their final destination, usually at the sides of the phalanges. The thumb, being independent has a special set of muscles devoted to it. The back of the forearm has a similar set for bending or extending the fingers and wrist.

In the hand itself there is a network of small muscles, ligaments and tendons which supply both stability and movement; the most important muscles, the *interossei* (pron. : inter-oss-ay-i) arise from the metacarpals and are inserted into the phalanges, so helping in bending the fingers. They are the muscles used in the childish trick of " separating your fingers."

MUSCLES WHICH MOVE THE LEG

The leg, of course, possesses the most powerful muscles of the body, especially those acting on the hip-joint (Fig. 36).

Coming from the sides of the lumbar vertebræ and the flat plate of the ilium—(the upper part of the hip-bone), is the *ilio-psoas* (pron.: 'illy-o-so'-ass) running across the hip-joint and bending the femur on the pelvis. Tuberculosis of the spine often tracks along this muscle to the surface. In the front of the thigh, there is the mass of muscle—the *quadriceps femoris*—which as we saw, collected its fibres and was inserted into the patella on its way to the tibia. Superficial to these is a band, like a broad strap, known as the sartorius which runs obliquely across to the inner side of knee and tibia. It is named thus from its being used in the days when the correct position for a tailor was cross-legged. It is also the longest muscle in the body. On the inner side of the thigh there is a group of muscles, the *adductors*, which move the thigh inwards. Sometimes these go into spasm, and so cause the legs to cross—producing " scissor-legs."

HOW WE STAND UPRIGHT

The back of the upper thigh, and buttock (Fig. 36) is formed be a very strong, coarse-fibred muscle, the *gluteus maximus* (pron. : gloo-ty-us), which sweeps from the sacrum to the outer side of the femur. This muscle enables one to stand upright, especially when standing on one leg, for it pulls back the whole pelvis, stopping it from tilting forwards.

Down the back of the thigh is the *biceps femoris*—two-headed like its fellow in the arm. This with two other similar long muscles forms the " hamstrings " at the back of the knee, on its way to be inserted into the fibula. To keep the knee straight as in standing, it is essential that these should be relaxed.

In the leg itself the muscles rise from tibia and fibula in a similar way to those in the arm. But the top of the foot corresponds to the back of the hand—and also incidentally the front of the leg to

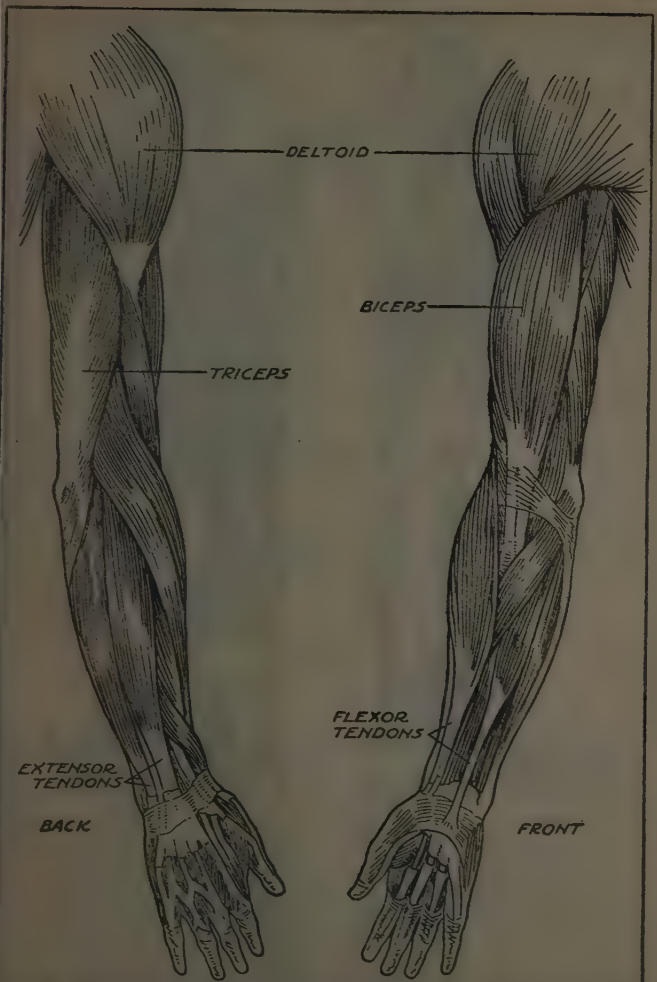


Fig. 35. Arrangement of the chief muscles of the arm seen both from the front and back.

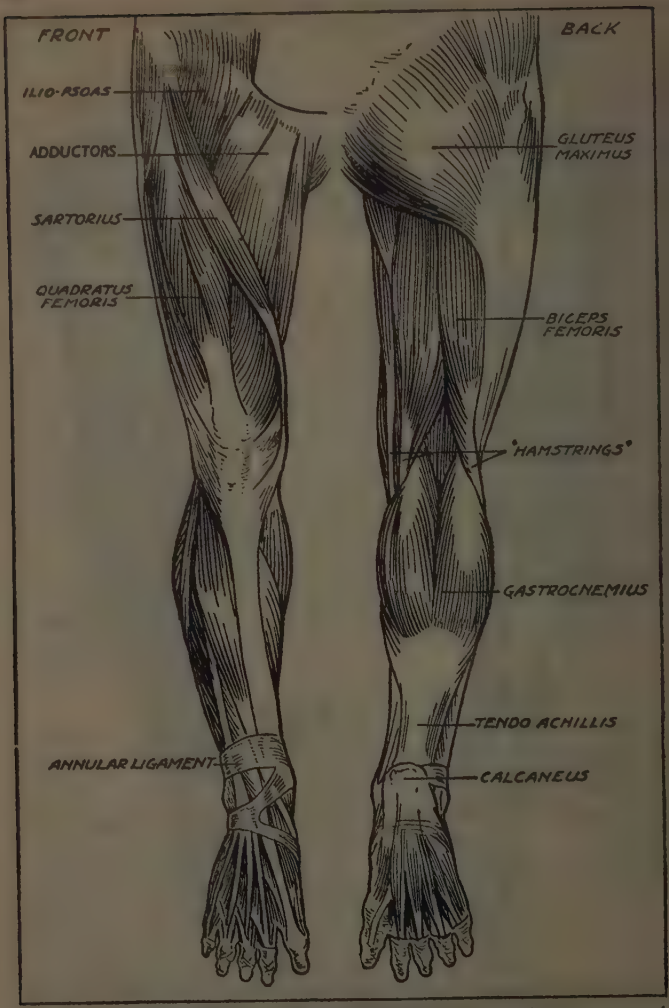


Fig. 36. *Front and back view showing how chief leg muscles are arranged*

the back of the arm. This is due to a twist round in the development of the limbs. Note also that the patella corresponds to the point of the elbow, and that with the arm straight, palm frontwards, the thumb is on the opposite side of the limb to the great toe. On the inner side of the front of the leg there are no muscles but only bare shin—the muscle bellies are placed on the outer side of the leg. Tendons pass down to the ankle, to which they are tied by a specially strong ligament, before they change direction and pass along to the toes.

At the back of the leg—the calf is formed by a large fleshy muscle —*gastrocnemius* which runs down, forming that very thick tendon you can feel at the back of the heel, to be inserted into the heel-bone or *calcaneus* (pron.: kal-kain'-y-us). This tendon was called the *tendo achillis*, because the Greek hero, Achilles, was vulnerable only in this part. The story runs that while he was a baby his mother dipped him in the River Styx, the waters of which made any mortal invulnerable, but she forgot also to immerse the heel by which she held him and eventually he was slain by an arrow which struck him in that spot.

Other muscles from the back of the leg send their tendons round the inner side of the ankle to the sole of the foot, where they pass to the toes. In the foot itself four layers of muscles form a complicated mass, as in the palm of the hand. There is, however, in this case, a very strong band of fascia, or fibrous tissue, binding the two ends of the long arch together—from heel to toes. This *plantar fascia* is of great importance in preventing "flat foot."

CHAPTER IV

THE BODY'S ARMOUR

HUMAN skin, delicate and vulnerable, would not be the first choice of most people if they were asked to make a suit of armour for the body. Why then has nature chosen it?

We mentioned before, that in the great reptiles, and even in the lobsters of today, the skin was modified into scales or horny plates; although the result was effective from the armour point of view, it had other great disadvantages and these creatures were some of nature's experimental failures. Let us consider why this was.

In animals the skin has two great duties to perform. Of course, first and foremost, it has to protect underlying organs from the accidents of everyday life. This includes not only blows and cuts, but the danger from ever-lurking bacteria.

Secondly the skin is a sensitive organ. After all it is by our skin that we touch objects, feel hot from cold, and above all

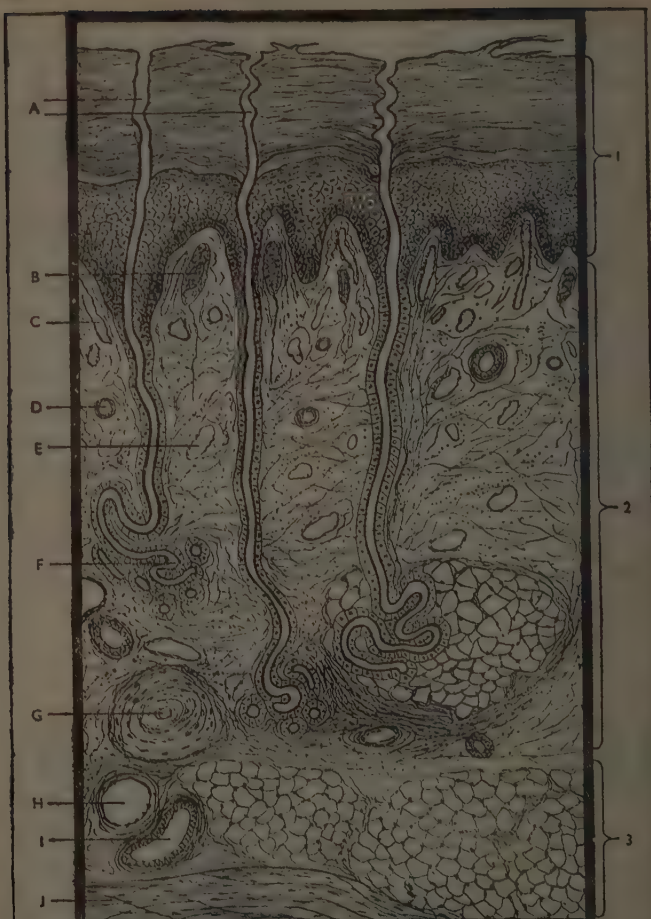


Fig. 1. *Section of the skin enlarged one hundred times. The three areas marked on the right are*: 1, *Epidermis or outer skin.* 2, *Cutis vera or inner skin.* 3, *Fat.* (a) *Sweat ducts;* (c) *capillaries or minute blood vessels;* (f) *sweat glands;* (h) *veins;* (i) *arteries;* (j) *muscle;* (b) *and* (g) *are the organs of touch;* (d) *and* (e) *are various particles of tissue.*

recognize something painful and therefore probably harmful to the body.

This second group of activities is denied to such animals as the lobster and the alligator, for their hard plates, though very good for protection, are quite insensitive.

Through the sensitiveness of our skins, therefore, we learn about our surroundings in a way a lobster cannot do—and knowledge is power.

The skin is, for this reason, richly supplied with nerves. These link up with other nerves in the central nervous system, so that messages can be sent to any part of the body in an instant of time.

In warm-blooded animals such as mammals and man, the skin, also plays a most important part by sweating and other devices to regulate the temperature of the body.

And lastly, it is beneath the skin that essential fuels of the body are stored until they are required—not to mention a very important vitamin, which is actually formed in the skin as well as stored there.

Already we begin to see the advantages of skin over scale.

THE STRUCTURE OF THE SKIN

In Fig. 1 you see the structure of skin. On the surface is a mass of dead cells, which flatten to form a horny layer. These dead cells, designed for mechanical protection, are continually being formed from the cells below them, and being shed—worn off by rubbing and other contact. The thickness of this layer varies in different parts of the body. It is thickest in those parts, such as hands and feet, which are continually rubbing and chafing against objects in their everyday life.

"Corns," for example, are formed at points where rubbing is excessive. A corn consists of layers of these horny cells piled up one on top of another into a pyramid. They have stuck together and not been shed as is usual. Consequently this pyramid of dead cells is formed. Further pressing from the ill-fitting boot pushes the point of the corn deep into the sensitive skin—so causing the pain. The corn itself is quite insensitive and incapable of appreciating pain—but not so the skin beneath.

THE THREE MAIN LAYERS

The skin (Fig. 1) is actually formed of three main layers; the *epidermis* on top, the *cutis vera* below it, and below this a layer of fat (3). The deeper layers of epidermis (Fig. 2) are composed of varying types of cells which all arise from the basal cell (E). This divides and produces the next layer of cells which have processes of cytoplasm bridging the gap from one to another, and are therefore called "prickle-cells" (D). In this layer the cells die and begin to flatten. Inside them collect granules of pigment, so that the

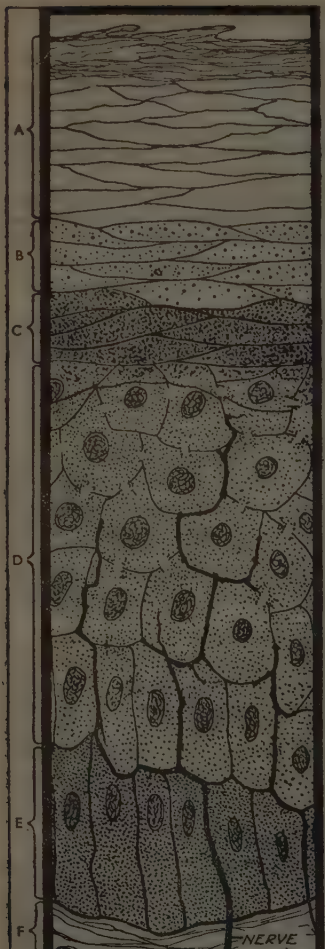


Fig. 2. Section of outer skin enlarged seven hundred times. (For lettering, see text.)

next layer is known as the *stratum granulosum* (C). Superficial to these the cells become clear *stratum lucidum* (B), gradually flattening and forming the horny cells *stratum corneum* (A) first mentioned, which are later worn off.

Pigment is formed also in the basal cell layer. It is this pigment which colours a negro's skin, and appears in our own white bodies after they have been tanned by the sun.

The *cutis vera* (F) or true skin is composed of connective tissue of a type rich in elastic fibres which stretch easily, so giving its suppleness to a healthy skin. As age comes on, these elastic fibres are replaced by tougher white fibrous tissue, which cannot stretch, and so the skin becomes drawn together in small folds—these are the wrinkles of old age.

The boundary line between *cutis vera* and epidermis is not straight, for there are spaces shaped like small bays, where the epidermis is invaded. These prominences of the cutis vera are known as *papillæ*. They serve to carry the essential small blood vessels or capillaries as well as being the common situation for the sensitive end organs of the nerves. In this place those serving the sense of touch are found.

Everywhere in the body, except in the palms of the hands and the soles of the feet, there are hairs scattered over the skin. Each hair is contained in a *follicle* (Fig. 4) which extends deep down into the cutis vera.

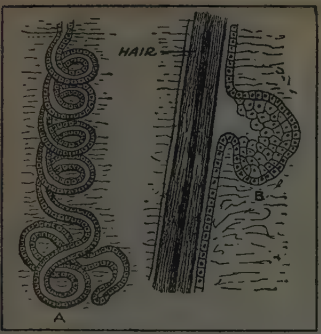


Fig. 3. *Enlarged sections of* (a) *sweat gland, and* (b) *sebaceous gland.*

Sweat glands also are distributed all over the skin, being most plentiful on the palms of the hands and the soles of the feet, just where hairs are most scanty. These glands are long coiled tubes which pierce the epidermis and open on to the surface (Fig. 3, A).

Sebaceous glands send their secretion into the hair follicle so lubricating it, and the skin around (Fig. 3, B).

We must now consider some of these structures in more detail. Hair, for instance, is an ingenious device to retain the heat of a warm body. When warm-blooded animals appeared on the earth the scales of reptiles were modified into hairs.

The hair of the body varies enormously in thickness and length according to its situation. For instance—in the skin of an eyelid it does not project from the surface at all, whereas from the scalp it may be some feet long. The colour of hair depends on the amount of pigment locked up in it. In old age this pigment often becomes scanty and its place is taken by colourless vacuoles, which reflect the light, thus giving the hair its white appearance, just as the foam of a wave looks white. There is no actual white pigment present.

THE DIFFERENT VARIETIES OF HAIR

Hair of course varies very much in the different races of man, from the curly-headed negro to the sleek-haired Chinese. A curly hair and flat hair look quite different under the microscope—the former showing a flattened oval, the latter a perfect cylindrical shape. Another interesting microscopic fact is the way one can often tell of a particular hair how long ago it was last cut. This is possible because of the way a hair grows after being cut, from a flat top to a rounded dome.

The distribution of hair over the body is very strongly influenced by a set of organs in the body known as the endocrine glands—or glands of internal secretion. For instance, the distribution in men of hair on the chin and face, as well as on chest and belly, is governed very largely by the development of the male sex organ or testes.

The section of a hair, seen in Fig. 4, shows a long shaft (A, B),

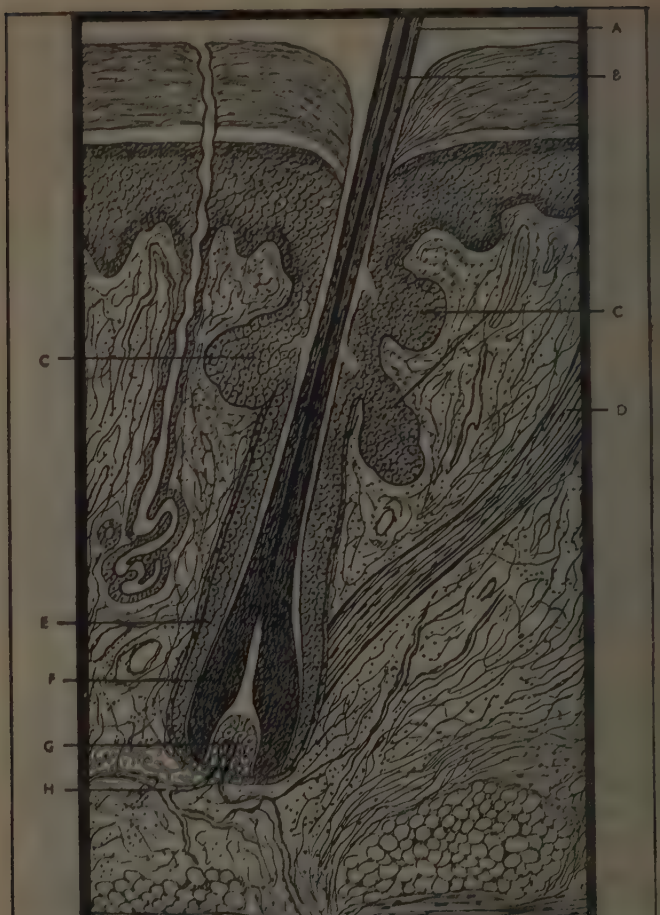


Fig. 4. *A sectional view of the root of a human hair enlarged one hundred times.* (a) *Wall or cortex.* (b) *Centre or medulla.* (c) *Sebaceous glands.* (d) *Muscles.* (e) *Sheath.* (f) *Hair bulb.* (g) *Papilla.* (h) *Nerves*

penetrating the epidermis and dermis (or cutis vera). This shaft ends in a bulbous expansion fitting over the hair papilla (G). The hair, as it passes down, lies in a sheath (E)—the whole forming a hair follicle. This follicle opens on the surface of the skin, whence it passes down sometimes straight, sometimes curved if the hair is curly, to end round the hair bulb (F). Opening into the funnel-shaped follicle near the surface are the mouths of the sebaceous glands (C) which keep up a continuous supply of natural grease to the hair. Sometimes this secretion—serum—becomes altered, perhaps as a result of invasion by a particular microbe. Then the hair loses its gloss and becomes dry and may fall out. The skin around also dies and forms scales which on the scalp are known as scurf or dandruff.

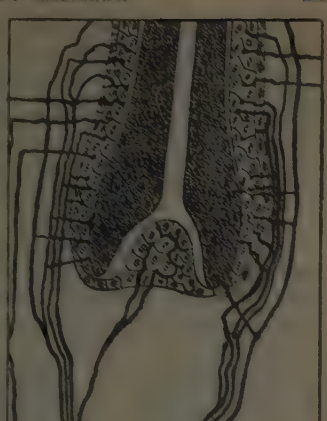


Fig. 5. The nerves of a hair.

Attached to the hair follicle may be seen a band of muscle, so placed that when it contracts, the hair will be erected from its oblique position. These, the *arrector pili* muscles (D), are responsible for the "bristling" of the tail of an angry cat. They are still present in man, but it is difficult to say whether the term "bristle with indignation" is justifiable or not. Cold also causes these little muscles to contract so producing "goose flesh." In furry animals this goose flesh, which indicates contraction of the little arrector pili muscles, would result in all the hairs standing out or bristling. This would mean that air would be caught in this forest of fur—so that it would remain in contact with the warm body of the animal beneath.

WHY HAIRS BRISTLE

Air is actually a bad conductor of heat, so that by bristling its fur in response to the cold stimulus, the animal has succeeded in forming a warm cushion all round his body. Around the base of the hair, particularly the bulb, there are many small nerve endings (Fig. 5). If the top of the hair shaft is touched even very lightly, leverage will transmit the stimulus to the region of the hair bulb, where the delicate nerves (Fig. 4, H) pick up the stimulus and register touch.

It is because of the presence of this rich nerve supply, that pulling out a hair is such a painful process.

The actual hair itself shows under the microscope as a hollow tube, and the wall or *cortex* (Fig. 4, A) in man is much thicker than the thin medulla (Fig. 4, B). This point is of importance in deciding whether a single hair belongs to an animal or a man. Microscopic examination of hair is sometimes of first importance in solving riddles of crime, as for example, in the Rouse murder case.

THE LAST RELIC OF OUR PRIMITIVE "FUR"

One last point about hair which reminds us of our humble ancestors! If you look at the hair on the back of your hands, you will notice that it all slopes towards your little finger. On your arm it slopes so that it runs upwards from the wrist, and downwards from the shoulder, coming to a point, so to speak, at the elbow. Why is it so arranged? In a four-footed animal, the foreleg is placed so that the thumb side comes in front of the little finger side, so that in walking, objects would not tend to get caught in fur, which was streamlined in this direction.

THE SKIN'S DEFENCE AGAINST GERMS

As for the arm, the same distribution of hair occurs in apes; and they are said to have been seen putting their arms over their heads so that rain runs down the forearms off at the elbow. The structure of the hair follicle renders it particularly prone to invasion by bacteria. As we mentioned, the skin always has bacteria on its surface, ready for any chance to pierce it, and invade the tissues beneath. The hair follicle forms a hole down which they can spread. Normally, the healthy follicle prevents this, but if owing, for instance, to a chafing collar, the follicle is slightly injured, then the resistance is broken, and the bacteria make the most of their opportunity. Multiplying in the broken follicle, they form a colony to which the body responds by inflammation—the result of which is a boil. It is because hairs are a weak spot in the body's armour that boils always tend to occur on hairy parts of the body. The back of the neck, where the hairs are injured by a stiff collar rubbing on them, is a favourite site. Usually the bacteria invading are staphylococci. The swelling, redness and pain of a boil are due to the increased flow of blood to the part, bringing a supply of the necessary *phagocytes* (pron.: fag-o-sites) to combat the bacteria. In the battle which ensues, some of the skin is killed, and forms the "core" of the boil. Bacteria and phagocytes kill each other in thousands—the white cells, as they die, liberating a substance that dissolves themselves and their foes. This is *pus*. Finally, the battle won, the wound is repaired, leaving perhaps a scar, and the skin returns to health again.

Though very simple structures, sweat glands are perhaps more important to civilized man than hairs. These glands consist of a coiled tube (Fig. 3, A) rolled up like a hose-pipe in the dermis, from which there runs a duct leading straight to the surface. These glands are especially frequent and large in parts which sweat easily, such as the arm-pits and groins.

THE CAUSE OF FINGER-PRINTS

They are also plentiful on the palms and soles. Here they open on ridges formed by the papillæ of the underlying dermis. It is this formation of papillæ and sweat-gland openings or "pores," which constitutes the "finger-print" (Fig. 6). The arrangement of curved ridges is quite peculiar to each individual. Three

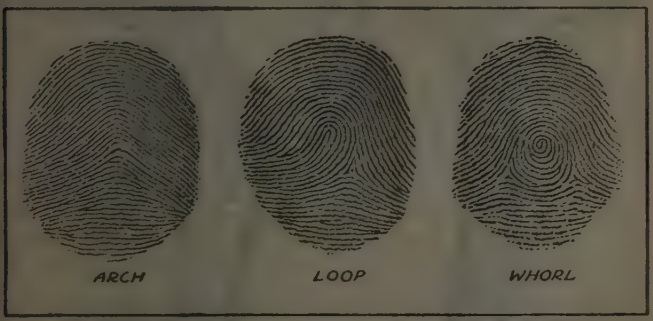


Fig. 6. *How sweat glands produce typical finger-prints.*

main types of pattern are known—the loops, the whorls and the arches. But apart from this, the sweat glands are of great importance because they constitute the most important cooling mechanism of the body. The sweat poured out on to the surface, evaporates; as it does so, it takes up heat from the body, so cooling it. The sweat glands work hand in hand with the blood supply. Let us see how the skin can increase or decrease the amount of heat lost by the body, for this is one of its vital duties.

The blood is supplied to the skin (Fig. 7) by microscopical vessels called *capillaries*, which run in the papillæ. These vessels have only one layer of cells in their walls, but they get their blood from slightly larger vessels called *arterioles* (little arteries), which have muscle in their walls. This muscle can be tightened or loosened as needed. If loosened, then there is a good flow of warm blood into the skin capillaries, and the skin becomes warm. If the arterioles are shut by their muscle, then blood flow is poor and skin becomes cold.

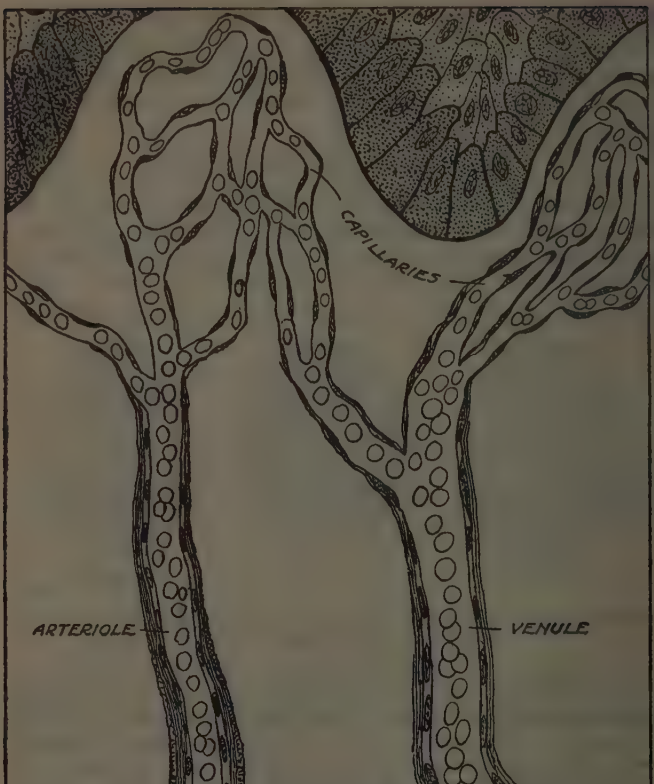


Fig. 7. The blood supply of the skin enlarged one hundred times.

It is the capillaries, however, which determine the colour of the skin. If they are widely dilated then the skin is full of red blood which shines through the epidermis giving a pink colour, or if the blood stagnates and does not flow—blue. If the capillaries are closed, there is but little blood present and so the skin is pale. So whereas the temperature of the skin depends on the arterioles, the colour depends on the state of the capillaries.

Now see how this mechanism works for temperature regulation

of the body. If the blood is too hot, the arterioles dilate and the capillaries are flooded with hot blood—the skin becomes hot and red, so that a large volume of blood is presented to the air (separated from it only by a few epidermal cells) to cool. Not only this, but sweat glands receive abundant blood, from which they secrete sweat which is poured on to the surface of the skin and is evaporated by the wind, so enormously aiding the cooling. Now the skin covers a large area, and can, if need be, very rapidly handle a large proportion of all the blood in the body and cool it down in this fashion.

WHY WE ARE HOT ON HUMID DAYS

Sweating of this kind can be brought on by heat from outside as on an excessively hot day, when the amount of evaporation depends on the dryness of the air. If it is a hot dry day, plenty of water is lost via the sweat, evaporation goes on apace and one is relatively comfortable. But if at the same temperature the air is moist or "muggy," then since there is already plenty of water in it, the difficulty of evaporating further water in the form of sweat is increased. Cooling of the body is less satisfactory. This is why hot moist days are much more uncomfortable than hot dry ones. Movement of the air also aids evaporation. For this reason electric fans are really useful in promoting comfort in a heat wave.

But sweating is also the mechanism of cooling the blood at the end of, or during a fever, when it is heated up within the body. Some very few people are so unfortunate as to possess no sweat glands. If the weather becomes hot they have to imitate nature as best they can by wrapping their bodies in wet clothes—the water taking the place of the sweat from their own bodies. These people realize only too well what normal people take for granted—what a splendid mechanism for cooling lies in our skins.

HOW THE SKIN KEEPS US WARM

Although the skin cannot do the opposite in cold surroundings, and make warmth, it can and does cut down the amount of heat escaping from the body. This time the arterioles contract, sending no more blood than necessary to the skin. Sweat glands are almost entirely inactive. The capillaries of the skin also shut down, so that in contrast to the previous instance the skin is now cold and pale, instead of hot and red. The amount of blood exposed to the cold air is a mere fraction of what it was before, and the heat lost through it is also very much less. Sometimes, however, if the cold is very intense, or the capillaries are not working as they should, the correct routine is not followed, and the arterioles may contract and the capillaries be paralysed so that they dilate. In this case blood stagnates in them, soon turning from red to blue as it loses its oxygen.

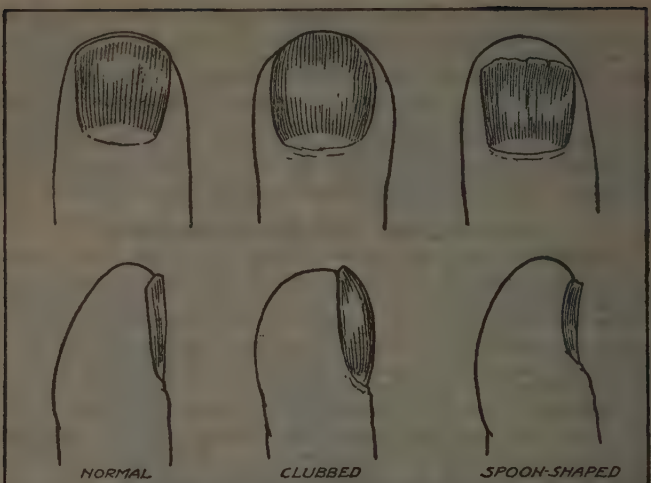


Fig. 8. *The finger-nails and how they are modified by diseases.* (*See text.*)

In this way a limb may become "blue with cold."

Specialized parts of the skin, at which we must glance, are the nails (Fig. 8). These consist of horny plates modified from the hard layers of the epidermis. These plates are quite transparent—the colour of one's nails being due to the very rich blood supply that lies beneath. In microscopic section the nail is seen to be embedded in the skin by its root. In this part the layer of horny material is thicker and more opaque. So, looking at it from above it appears white, forming the "half-moons." The nail grows in this portion, pushing the rest towards the tip of the finger, so that the edge gradually comes to lie over the end of the finger—the nail becomes "long." A whole new nail is formed from the half-moon in this way about once in six weeks. But rate of growth depends on general good health. In some diseases, particularly those of the chest, nails tend to become rounded and "clubbed" in advanced cases, so as to look like drum sticks. In some forms of anæmia they become very brittle and hollow, so that they may look like shallow spoons. General ill-health may be reflected in white lines across them or coarse vertical furrows.

In the substance of the skin are the endings of nerves designed to appreciate the various forms of stimulation which we know of as pain, heat and cold, and touch. Pain being the most primitive of

ne sensations, is represented by
ne most primitive form of nerve
nding. For naked nerve fibres
enetrate right into the epidermis
nd lie between the cells of the
rickle-cell layer (*see* Fig. 2)—
ese are the fibres that pick up
ain stimuli.

More delicate sensations such
s those of touch, are appreciated
y more elaborate apparatus.
ut, although the construction of
ese end organs varies for differ-
nt types of sensation, they are all
uilt upon the same ground plan.
ound the sensitive bare nerve
nding (Fig. 9) there are wrapped
veral layers of tissue, like the
ats of an onion. These modify
ne stimulus so that it is picked
p by the sensitive nerve lying in
ne middle. End organs of this
nd are found plentifully in the
in, and in the muscles and
ndons also.

In these days when sun-bathing
as become so popular, it is
portant that one should know
st how the rays of the sun affect
e skin. For the sun is a powerful
rce, and as such can do harm
well as good.

The rays of the sun consist of
eat, light, and ultra-violet parts.
hese rays travel in waves, just
ke the waves which travel across
still pond, when a stone is
opped into it. Those which
nvey heat have the longest
ave-length, that is, the ripples
n the pond are farthest apart.
he longest of the light waves is
d, and it is because of this that
hen a poker is heated in the
re it becomes "red" hot and
ot green hot or any other colour.

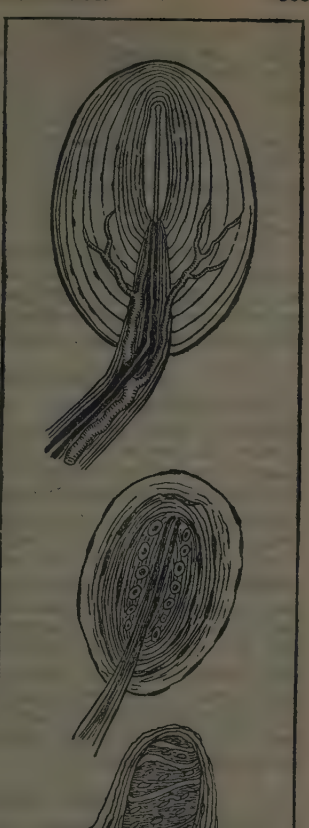


Fig. 9. The end organs of nerves enlarged 250 times.

As one passes through the colours of the rainbow—red, orange, yellow, green, blue, indigo, violet—the wave-length, and length from crest to crest of wave, become shorter, the ripples on the pond become closer. At violet the eye can still see them. But shorter than this, it fails to detect them—they have become ultra-violet—beyond the violet end of the spectrum just as the heat waves were beyond the other, the red end. Now sunlight contains all these varieties of ray which differ only in their wave-lengths. It is the ultra-violet rays which act particularly on the skin producing tanning, or sun-burn. Probably you have noticed that the effect of sun-bathing is often not felt until some hours afterwards. In this lies its danger. For one may lie in the sun comfortably for hours on end, and it is not until going to bed that night that the skin begins to smart, and perhaps a sensation of feverishness develops, often accompanied by a rise in temperature.

SOME DANGERS OF SUN-BATHING

The skin reddens, it may even blister—and a few days extreme discomfort ensue before the victim has learnt his lesson. These ultra-violet rays act chemically in the cells of the skin, and these chemical reactions take time to develop. Normally, in small doses the reaction stimulates the body, and a feeling of well-being is experienced which is the goal of sun-bathing. But like other stimulants, if taken in an overdose, ultra-violet rays become an irritant to the tissues, the skin becomes inflamed, with the inevitable discomfort and harm that accompanies inflammation. The moral is start your sun-bathing gradually, a few minutes only at first, working up to longer times as your skin gets tanned. The fairer you are, the less well can you stand sun-bathing. Fairness is due to lack of pigment in hair and skin, and although it may confer many advantages in complexion and delicacy of skin, it does not confer the ability to withstand sunshine. Fair people get "burnt" much more often than they get tanned, and must start their sun-bathing all the more cautiously.

WHY THE SUN TANS US

Tanning is due to the creation of pigment in the basal cells of the epidermis. This is produced in response to the stimulation of the ultra-violet rays, and protects the sensitive tissues beneath. This process has gone on so long in peoples, such as negroes, who inhabit the tropics, that they are born with an extra supply. In consequence their skins are dark by nature.

There is another action of ultra-violet rays in the skin, discovered only during the last few years, and of great importance to the welfare of the body. This is its power to form from the fatty substance found in the skin, one of the vital vitamins. This vitamin D is of great

mportance in the growth of bone, and although it may be taken nto the body in the form of food, the supply can be supplemented oy the action of sunlight.

WHAT IS SWEAT?

One has often heard the expressions " to sweat it out of you," ised in the belief that various poisons of disease can be got rid of hrough the skin. If this were so, it would obviously be through he sweat, though in lower animals such as frogs there is evidence or saying that gases can be loosed from the blood and pass through he skin into the air. In this particular it is safe to say that frogs nave the advantage of men. Human skin is thicker than a frog's—oo thick for any appreciable quantity of gas to pass through it directly. But with sweat it might be another story. Perhaps, when you have been sweating profusely, you have licked some sweat off your lips and noticed that it had a salty taste. Actually, on chemical analysis, sweat is found to consist of about ninety-nine per cent water, with some *sodium chloride* (common salt), and other substances in minute proportions, including a substance called *urea*. Sweating does of course form a way of getting rid of water from the body. And the water balance of the body, whereby the amount taken in in food and drink is adjusted to the amount put out in urine, lungs and sweat, is a very delicate process, the study of which has only of recent years received the attention it deserves.

Excessive sweating can and does upset this balance. One notices that the more one sweats the less urine is passed, and the small amount that is excreted via the kidneys becomes therefore very concentrated and highly coloured.

But the evidence that the skin can excrete poisons in any significant amount is not strong. The substance urea which we mentioned above is of the first importance because it is derived from the waste products of absorbed food and cell life, and so must be got out of the body. This the kidneys do in health. But in cases of kidney disease the kidney may fail in this function, and the urea may pass out in the sweat—in rare cases in such quantity that white crystals of it form on the skin. Unfortunately this is never sufficient to help the patient, who in such a case invariably dies.

WHAT THE SKIN CAN ABSORB

The opposite to excretion is absorption. Is there any evidence that substances can be taken into the body through the skin?

Here the story is different. For in some cases drugs administered as ointments, certainly can and do find their way into the blood and so into the whole body. Perhaps the best example is a mercury ointment which is used in this way. But the number of examples

where this occurs is not very many, for after all it is one of the main functions of the skin to guard the body from chemical invasion. Where should we be if our skin absorbed all the poisons with which it came into contact?

Some substances can be pushed into the skin by making them part of an electrical circuit through the skin—a process known as *ionization*. By this method drugs can be "inserted," so to speak, near to a diseased joint. But this method of administration is obviously of very limited use. More often drugs are administered by *hypodermic* injection (*hypo*—under, *dermic*—the skin). In this way the barrier of the horny layers of the skin is avoided, and absorption of the drug from the blood vessels in the fatty layer beneath is very rapid.

One of the old-fashioned methods of giving drugs through the skin was to "blister" it first, and then apply the required ointment

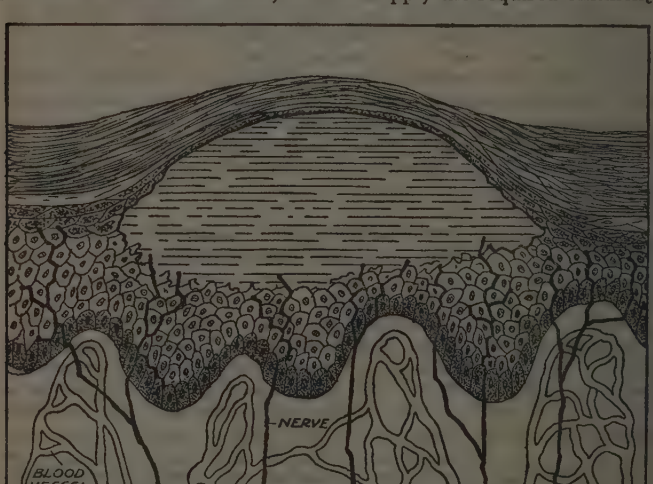


Fig. 10. *Sectional view of a simple blister on the skin enlarged* 150 *times.*

or dressing. This was known as an *endermic* application. A blister is formed by a split in the prickle-cell layer of the epidermis (*see* Fig. 10). Into this layer, as a result of irritation, whether it be from a rubbing shoe or a mustard plaster, there exudes fluid. This collects, forming a round watery globule whose roof is the horny layer of the epidermis, and floor the basal cells. Usually the fluid

in a blister is clear, but if the injury has been severe, such as hitting the skin with a hammer, then the basal cell layer may be broken, and blood flow out through this layer into the prickle-cell layer, so forming a "blood blister." You will have noticed that the white skin over a blister is insensitive. This is because the collection of fluid has, in raising up the superficial layers of cells broken all the small nerve-fibres to them; they have therefore lost all power of feeling.

HOW THE SKIN REACTS TO DISEASE

The skin plays a large part in the body in its reaction to disease. Pallor of the skin may be due to two causes: either that the person is anæmic, or that the small capillaries are contracted down so keeping blood out of the skin. The second type of pallor is often seen in tall, thin, nervous people who are restrained and "locked" in. In these people pallor often does not indicate anæmia.

Then the skin, perhaps as much as any other part of the body, reflects any disturbance of the glands of internal secretion. It is almost incredible that a skin, hard, dry and scaly can be made smooth and moist by merely giving someone a few tablets of dried thyroid gland. But it can be done.

Again, with many diseases the skin gives evidence of being affected. Look at the rashes of measles, scarlet fever, chicken-pox for example. What is the skin doing in these diseases? Is it mere chance that for the most part, when these rashes appear, the worst of the illness is over? Or is the rash some indication that the skin is actively engaged in preparing substances to neutralize the disease poisons that are flowing in the blood? For surely it is remarkable that in so many of these diseases, one very rarely gets a second attack.

THE EFFECT OF FOOD POISONING ON THE SKIN

Have you ever had a meal of lobster, oysters or some other food, after which you have come out in an intensely irritating rash all over the body—a kind of "nettle-rash"? Most people have had an attack for some reason at some time of their lives. It is another example of how the skin is linked up with the rest of the body system. These wheals are due to a poison (and remember one man's meat is another man's poison) absorbed from the gut, injuring the small capillaries beneath the skin, which let out their fluid into the tissues. This fluid raises the skin surface in a similar way to a blister, except that it is in the true skin, deeper down. So it is that the wheal comes up and goes down in a few minutes. The injury is of exactly the same nature as a true nettle sting, where the sharp point of the leaf, the hair, pierces the armour of the epidermis and is broken off, liberating from inside the stinging *formic* acid—the same acid that is used by stinging ants.

The skin also responds to some drugs and poisons taken by mouth, some of which impart their odour to the skin, as they are excreted by it. Perhaps the most interesting in this connection are arsenic and silver.

THE EFFECT OF OTHER POISONS

Arsenic is by no means limited in its uses to poisoning. It is a very useful drug when given in the correct dose. Its good effect on the skin and complexion was well known to ladies of fashion in times past. But they probably had the mortification of discovering other things about the drug too. There is no doubt, that temporarily the skin becomes soft and clear, the hair silkier and glossier under its subtle influence. After this, less pleasant things happen, for the rejuvenation of skin cells gets out of hand, and the production of the horny cells is speeded up, so that patches of horny masses like flat corns arise in various parts of the body, scaly rashes appear, some of them peculiarly obnoxious. Finally, to complete the disagreeable picture, patches of black pigment stain the skin, forming a pattern like raindrops on a pavement. It should be noted that these are the effects on the skin only. Arsenic poisoning of the slow type has various other painful ways of expressing itself. In all these cases, arsenic is found in the skin and hair after death, and beautifully delicate chemical tests are available whereby the amount can be accurately estimated.

However, in some people an amazing tolerance to the drug is found, and peasants in Styria in the past took the drug regularly to help their endurance in climbing.

The second drug, silver, has a less dramatic effect in that its action is limited to pigmentation. A layer of grey silver salt is deposited beneath the skin, which imparts to the victim a peculiar blue-grey tint, lasting for the rest of life, whatever may be done. There is no doubt that silver is much more pleasant in the pocket than in the skin.

Drugs applied to the skin are usually not meant to be absorbed but to act as " counter-irritants " to relieve pain in deeper lying organs. An example of this is the mustard plaster.

One substance applied to the skin for its local action—and very important it is in skin health—is soap.

SOAP AND ITS VALUE TO THE SKIN

Soap is composed of fats and alkalis. The finer the soap the less the alkali there is in it. " Soft soap " has a large quantity of these caustic substances in it, which dissolve dirt extremely well, but unfortunately also dissolve the skin—so that if it is used for washing, soreness and discomfort speedily result.

Soap acts by forming with water a " lather," which consists of

infinitely fine air bubbles locked up in films of fat. The whiteness is due to the reflection of light from these small spaces just as is the whiteness of hair.

These small bubbles force themselves into the smallest crevices of the skin, lever up loose scales, attract by absorption particles of matter called dirt—so cleaning the pores far more efficiently than any mere surface application of water could do.

HOW SOAP CLEARS OUT BACTERIA

Bacteria also are discouraged by soap; they are turned out of their holes and lairs, not only by the pushing of the minute bubbles, but by the trace of alkali which even the best soap possesses. This, combined with special antiseptic incorporated in some soaps, such as carbolic acid, makes the bacteria particularly uncomfortable.

The object of a good soap then is to make a good lather to dissolve dirt and kill bacteria. It must not injure the skin in any way, interfere with the function of the sweat and *sebaceous* (pron.: sab-ace-ius) glands, or upset the growth of hair on the part washed. A good soap is therefore a work of art.

HOW THE SKIN HEALS AFTER A CUT

Most of us have cut our fingers at one time or another, and it is of interest to see how the skin heals after such a wound. If a knife, for example, penetrates the skin for a short distance, it destroys and kills the cells in its path. As they die, these cells become a stimulus to their living neighbours, so that in a short while the edges of the wound become red—blood vessels; capillaries are being formed on each side of the cut. From these capillaries there is an exudate of sticky fluid, *fibrin*, and white blood cells, or *phagocytes*. This sticky substance sticks the two edges of the wound together temporarily. Meanwhile connective tissue fibres from around, invade the temporary scaffolding of fibrin. These cells are called *fibroblasts* or young fibrous tissue cells. They stream into the medium of fibrin by a kind of amœboid movement. Once there, they settle and lay down a firm substance, *collagen*, all round them, becoming mature fibrous tissue cells. This collagen is laid down in wavy masses. As it appears it constricts the small blood vessels—so that the scar which was in its early stages pink and raised above the surface, in the course of time becomes white (no blood vessels) and puckered (contraction of the fibrous tissue cells). While this is going on the epidermis grows over the gap where it was broken—but does not form complicated structures like hairs and sweat glands—so that within a few days all that is to be seen of the wound is a thin line of pale connective tissue. It is a masterpiece of quick repair.

Now we have caught a glimpse of some of the things the skin

does, our respect for this quiet everyday part of the body which divides us from the world outside, must increase. True it is the body's armour—but in how much deeper a sense than usual of the word "armour." It is a protection from the blows and buffets of the world—yes—but also a "feeler" always scouting out the surroundings. How should we move in a dark room without it?

CHAPTER V

THE BODY'S PUMP

In 1628, William Harvey, physician to Charles I, published a small book of seventy-two pages. In it he described his reasons for putting forward the statement that blood travels round in a circuit —from the heart, back to the heart. Harvey had come to this conclusion only after many years of experiment on animals, and dissections of human bodies.

To get a glimpse of the mind of this man, who made the greatest discovery of all medical science, let us look at the opening of his book, *Anatomical Studies on the Motion of the Heart and Blood*. In a chapter entitled, "The Author's reasons for writing," he begins: "When I first tried animal experimentation for the purpose of discovering the motions and functions of the heart by actual inspection, and not by other people's books, I found it so truly difficult that I almost believed with Fracastorius, that the motion of the heart was to be understood by God alone." With what quiet triumph does he arrive at the conclusion that "The heart alone is so situated and constructed as a reservoir and fountain, that blood may be apportioned from it and distributed by its beat to all regions according to the size of the artery serving them."

WHY BLOOD CIRCULATES

The object of the circulation of the blood is to ensure that all the cells of the body shall be regularly supplied with food and oxygen, and regularly cleared of poisonous products.

To achieve this object an intricate network of tubes run throughout the body. These tubes are of two types, known respectively, as arteries and veins. They vary enormously in size. The biggest is the artery known as the *aorta*, the main supply pipe leading directly out of the heart, from which eventually all the parts of the body are supplied with blood. The smallest are minute vessels known as capillaries, so small that they are only visible under the microscope.

In the centre of this network of tubes and blood vessels lies the heart. Its function is to pump the blood round and round on its never-ending journey. Fig. 1 shows how this system of pumping

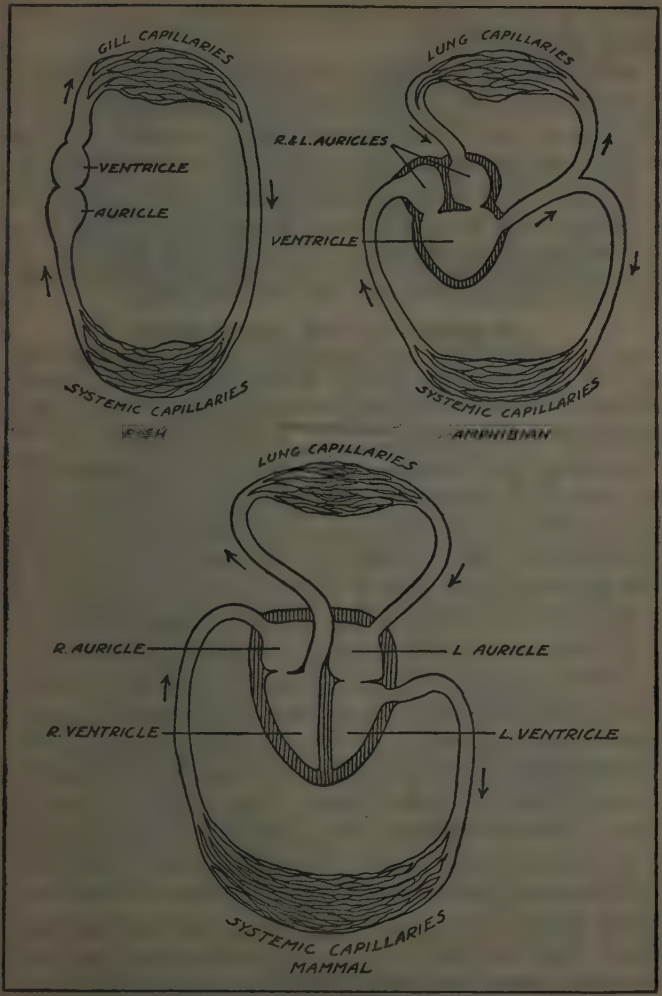


Fig. 1. The heart and the blood circulation.

works in the case of fish, amphibian and mammal. It will be seen that, in the last system, the heart is a much more complex device than in the others.

Before examining the detailed working of this system, let us trace it in general outline. From the heart, the blood is pumped along the tubes known as arteries, to the capillaries from which the tissue cells, such as muscle and fat, of the body are supplied. From the capillaries the blood is returned to the heart by the tubes called veins.

When this blood, which now is full of impurities collected from the tissues of the body, reaches the heart again, it is at once pumped out into the lungs, where it can absorb oxygen, which the lungs have breathed in from the air, and recover its life-giving properties. It is then returned to the heart and is, once more, pumped out through the aorta, on its long journey to every part of the body.

THE DESIGN OF THE CIRCULATION

You will note that the circulation is not simple; it consists much more of a figure of eight design. In fact, there are two separate circulations, away from, and back to, the heart. One, the "greater," goes to tissues, limbs, internal organs, and back to the heart; the other, the "lesser," goes through the lungs only, and back to the heart.

This design of the circulation was not always so. In fishes, as you can see in Fig. 1, the circulation does consist of a simple circle. The heart is a simple tube divided into two beating chambers which pump out blood into the gills, where oxygen is obtained from the water, the blood flowing on from here to all parts of the fish's body and so back to the heart. In frogs, the heart is three-chambered, and a simple lung circulation exists : it is only in mammals that the heart is divided into four chambers—two on the right separated from two on the left—in which valves control the direction of the flow of blood.

Although, as we saw, the tubes which carry the blood vary in size, they are all elastic and contract or expand according to the pressure of the blood inside them. In the arteries the pressure is naturally much greater than in the veins, for it is the former which directly have to stand the rush of blood, as it is pumped out of the heart.

This ability to expand is derived from the muscles and the elastic tissues of which their walls are made. This can be seen clearly in Fig. 2. The small capillaries contract and expand according to the needs of the cells around them; the veins do not expand much, being relatively passive canals for blood to flow back to the heart. Inside them an ingenious system of valves prevents the blood from flowing backwards.

With this knowledge of the circulation, we can understand how Harvey found first, that the valves of the heart and veins permit of movement in only one direction; secondly, that when the heart is seen and felt to contract, the arteries expand; thirdly, that if an artery

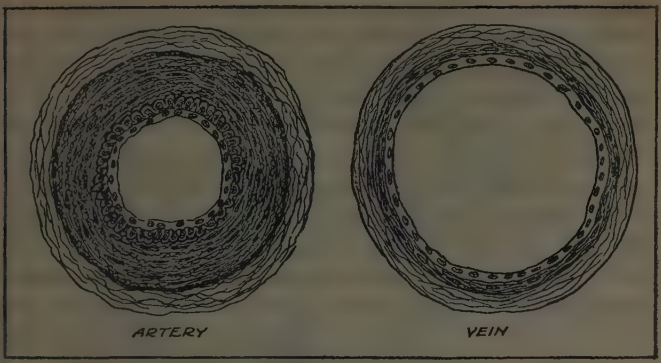


Fig. 2. Transverse section of blood vessels of the body.

is cut, blood spurts from the end at each heart beat. Finally, he reasoned, if the blood that is expelled on each contraction of the heart left the body, there would soon be none left.

Therefore it cannot leave the body and must return to the heart.

Harvey never knew of the actual existence of small channels, the capillaries, connecting arteries with veins, for in his day there were no microscopes to see them. On this very point his critics fastened with leech-like intensity : but Harvey boldly defended his guess that, although he could not see them some such channels must exist. He was right. In 1661, Malpighi, peering down his microscope, discovered these channels.

THE NATURE OF THE HUMAN HEART

The heart is composed of muscle of a special type. We saw in Chapter I that there are two main types of muscle in the body, those of the voluntary or skeletal system, which have layers across them and are called "striped," and the "plain" or involuntary muscles found in such organs as the gut, which are unstriped. Heart muscle is a mixture of the two—its fibres are striped, but they branch, one joining another so that the heart is a continuous sheet of muscle —not a collection of separate fibres.

This muscle has most important properties, for in it lies the secret of rhythm. What makes the heart beat? The beat as we call it, is simply a contraction of the muscle and in normal human beings that contraction occurs about seventy-two times a minute. It follows, therefore, that those muscles must receive a stimulus to contract seventy-two times every minute. Without this stimulus they would remain still and the heart would not beat.

Why should this rhythm be kept, why should this mysterious stimulus recur seventy-two times every minute? To these questions there is, so far, no complete answer. All we can do is to point to a centre from which the impulse takes its source, and trace its progress through the heart muscle. Before we examine this mechanism, however, let us study this process of heart-beat a little more closely and in greater detail.

Like other forms of muscle that of the heart responds to a stimulus. Now a law of muscle is that if it responds at all it does so to its utmost. This is known as the " all or none " law. If an impulse passes, for example, to the biceps muscles—those fibres affected contract to their utmost, or not at all. The fact that one can exert a varying amount of force with one's biceps is simply due to the varying number of

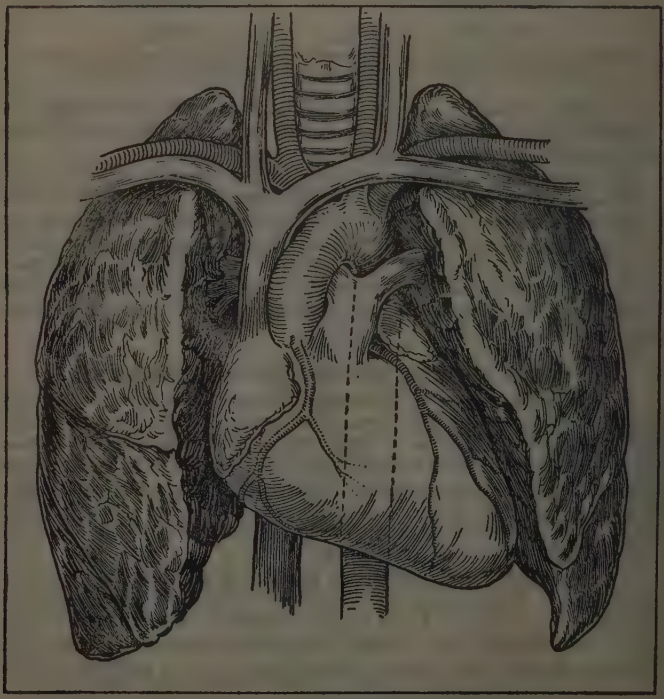


Fig. 3. The human heart in position between the lungs.

fibres contracting. All those that do contract, do so completely. But in the case of the heart we notice that each muscle fibre branches and joins its neighbours, so that as far as contraction is concerned, the heart is just one colossal muscle fibre. When the heart contracts at all then, it does so to its utmost. Each contraction lasts about three-tenths of a second. If another stimulus is sent down in less than this time, the heart does not respond : it is not at that moment excitable, being in what is known as the *refractory period.*

As the contraction relaxes, however, so the excitability increases, and the stimulus will take effect. Since this variable state of excitability exists the heart cannot beat in a normal fashion at a rate higher than about two hundred per minute.

Sometimes the stimulus arrives out of its turn, so to speak, and the heart responds so that its beat becomes irregular. This irregularity, known as " premature contraction," occurs in about twenty-five per cent of healthy people and is a perfectly normal occurrence.

The heart of man (Fig. 3) is about the size of the closed fist of its owner, but there is a fairly wide variation in " normal " size. It lies obliquely in the chest, beneath the sternum or breast-bone and between the lungs, projecting rather more to the left than to the right, so that its tip can be felt beating against the chest wall about three and a quarter inches inside the left nipple.

Round the heart is a bag of fibrous tissue—the *pericardium* (pron.: perry-kar'-di-um). The surfaces of the pericardium and the heart are always well lubricated with fluid so that they can move over each other smoothly during its beating.

THE HEART'S FOUR CHAMBERS

If you look at Fig. 4 you will see a cross-section of the heart. You will notice that the cavity inside is divided into four chambers. It is first divided lengthways down the middle into two parts, by a wall of muscle known as the *septum.* Each of these chambers is also divided into two other chambers, a smaller and a larger. These are known respectively as *auricle* (pron.: aw'rikel) and *ventricle* (pron.: ven'-trikel). Inside the heart there are therefore four chambers; a right and a left auricle in the top half, and a right and a left ventricle in the bottom half. Notice, however, that while the pair of right-hand chambers are completely separate from the pair of left-hand chambers, neither the two right- nor the two left-hand chambers are wholly separate one from the other. You will see, in Fig 4, that a narrow gap, situated between two tongues of fibrous tissue, leads from the right auricle into the right ventricle. These are, in fact, the valves already spoken of, the function of which is to control the direction in which the blood in the heart flows.

Now let us try to understand the part played by each of these chambers in the circulation of the blood. Let us start as before,

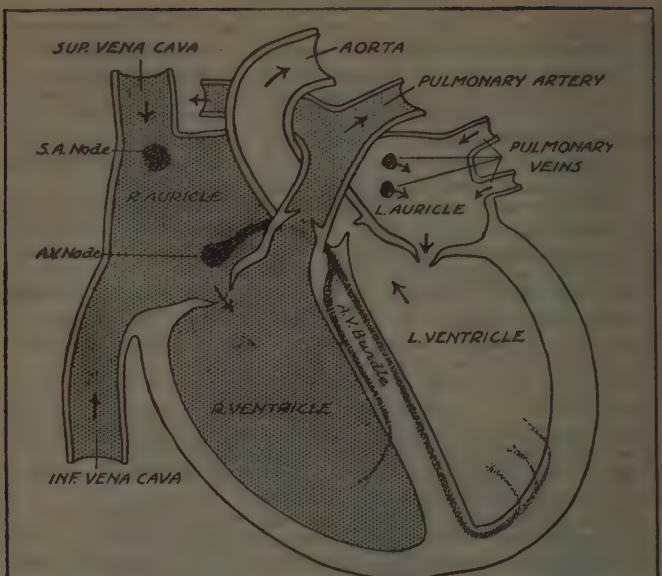


Fig. 4. *Transverse section of the human heart.*

with the blood that is brought back from the cells and tissue of the body to the heart. This blood, exhausted of oxygen, which it has distributed to various organs and limbs, is collected as we saw, in veins. These veins lead into one another, the main ones gradually growing larger, in the same way as a river fed by its tributaries. As the heart is approached only two main veins are left.

The first of these, called the *superior vena cava*, is seen top left, in Fig. 4. It brings to the heart the blood collected from the upper limbs and head. The second, the *inferior vena cava*, seen below it, carries the blood collected from the lower limbs and trunk of the body.

Both of these main veins discharge, as will be seen, into the right auricle of the heart, which is connected with the right ventricle by a valve known as the *tricuspid* (pron.: try-cuss-pid) valve (so-called because it has three cusps or pointed flaps). As the ventricle expands after the contraction of a heart-beat, so the blood is drawn or sucked into it from the auricle. Then, when the next contraction of the heart occurs, the blood now in the ventricle is pumped out. It cannot return whence it came, for the valve is automatically closed by

the contraction of the heart; it is therefore pumped out into a strong tube known as the *pulmonary* (pron.: pul'-mon-ary) artery, which leads directly to the lungs. Another valve at the entrance to this artery prevents the blood returning to the heart.

In the lungs, the blood takes up oxygen, which changes its colour from dark red to bright red; it then passes back to the heart along two veins from each lung. These four pulmonary veins enter the left auricle (as will be seen in Fig. 4), where the blood is collected and passed through the *mitral* valve (so called because its two valves make a shape like a bishop's mitre) into the left ventricle.

HOW THE VENTRICLES REGULATE THE FLOW OF BLOOD

Whereas the right ventricle has only to exert sufficient force to send its blood through the short pulmonary circulation, the left has to send blood all over the body—from the head to the toes. For this reason its walls are considerably thicker than those of the other, as you see in Fig. 4. When the heart contracts again the blood is passed through another valve into the aorta, the great main artery of the body. This closes when the heart has finished its contraction, so preventing blood from leaking back into the ventricle. The arrows, in Fig. 4, show the direction of the flow of blood.

It will be seen from this account that the two auricles have, as their function, the collection of blood. They contract only to send their contained blood through valves into the ventricles. For this reason, they are thin-walled chambers with only a small amount of muscle in them.

The auricles are separated from the ventricles by a ring of fibrous tissue which joins them to the valves and to the mass of heart muscle. On account of the peculiar spiral sheets, both cross-ways and length-ways, in which the muscles of the heart are arranged, they contract when they work with the maximum efficiency in expelling the blood.

THE "CARDIAC CYCLE"

Now let us commence right at the beginning of a heart-beat and follow up what happens in the heart until the next beat is signalled—or, in other words, let us trace out what is known as the *cardiac cycle*.

We saw that the heart muscles contract, following a stimulus, seventy-two times every minute, and we stated that the source of this nervous stimulus could be located. In Fig. 4 you will see this source, it is marked as the "S.A. node" high up in the right auricle. "S.A. node" is a short expression for *sino-auricular* node. In effect, it is a centre of importance frequently referred to as the pace-maker. From this point the impulse which regulates the heart-beat then starts on its journey. First, it spreads in all directions over the

auricles, coming back in the end to another point, the *auriculo-ventricular* node (A.V. node) situated just below the S.A. node, still in the right auricle.

Why should the impulse do this? We mentioned before that a fibrous ring separates auricles from ventricles. Delicate impulses cannot pass this obstacle, and there is only one small strip of very special tissue—clearly marked, in Fig. 4, as the "A.V. bundle"—along which it can go. This bundle of nerves passes from the A.V. node down the division between the ventricles. After a short course it divides into two branches, one passing to the muscle of the left ventricle, the other going to that of the right ventricle. The impulse carried along this course, conveys the stimulus to contract. This the ventricles do, the apex or tip of the heart contracting just a fraction earlier than the base. This assures that the blood is expelled with the utmost efficiency.

WHAT HAPPENS WHEN THE HEART CONTRACTS

The sudden rise of pressure in the ventricles on contraction (a process known as *systole*), closes the inlet valves of the heart. These valves are prevented from being blown inside out by strong attachments (called *chordæ tendinæ*) (pron.: kor'dy-ten'-diny) fixed to the wall of the ventricle and acting in a similar way to the ribs of an umbrella. Quickly the pressure in the ventricle rises, until the outlet valves open, and the contained blood is ejected. This continues so long as the pressure inside the heart is greater than that in the main arteries, either the pulmonary or the aorta. As the ventricle ceases to contract, the pressure within falls, aortic and pulmonary valves snap to, and no more blood passes them in either direction. Relaxation or *diastole* has begun. As the ventricle relaxes further it produces a concertina-like action so that the inlet valves are drawn open. Blood that has been collecting in the auricles is now sucked through these valves into the ventricles. This flow goes on until the pace-maker sends out another impulse over the auricles, which contract in response, thus sending a further jet of blood into the ventricle.

The new impulse follows down the A.V. bundle, as we have described, and another ventricular contraction begins. The cycle of the heart action is complete.

The time taken by the whole of this cycle of events is less than one second. Three-tenths of a second is occupied in contraction of the chambers of the heart, about four-tenths in the resting period. When the heart rate quickens, as in exercise, the period of resting becomes shorter, whereas contraction time remains relatively unchanged.

When the right auricle beats, the wave of pressure within it is carried along the great veins, so that in a thin person, careful inspection of the great vein (known as the jugular) in the neck, will show

that there are two pulsations for each heart-beat. One of these is due to the auricle contracting and sending its blood into the ventricle, whilst, owing to the fact that there are no special valves between auricle and the main inlet veins, a small gush of blood flows back into these veins, thus setting up a pulse visible in the neck. Less than one-fifth of a second later the ventricle contracts. This makes the neck artery pulsate, which, in turn, is shown in its neighbouring jugular vein. So from examination of the neck a great deal can be learnt of the action of the auricles and ventricles. Sir James Mackenzie in devising a special machine for making tracings of these neck pulsations early this century, made a great stride in the understanding of heart action.

EARLY EXPERIMENTS ON THE HEART

As the heart contracts, its base moves sharply downwards, but the apex hardly moves at all. This fact was first discovered by Leonardo da Vinci, who, amongst his many other activities, enquired into the mystery of heart action. This was more than a hundred years before William Harvey discovered the secret of blood circulation. Leonardo da Vinci put needles into the heart through the chest wall, one in the base, one in the middle, and one at the tip, and noticed that the first moved down sharply, the second less, the third not at all.

If you put your hand over the left chest near the nipple, you will feel the heart beating. This beat, known as the *cardiac impulse* is of great importance, in its character, to doctors. It is produced by the soft muscle walls of the ventricle beneath tightening up suddenly as they contract.

THE HEART AND ITS BEAT

If you put your ear to the front of the chest or listen with a doctor's stethoscope, you will hear two heart-sounds for each beat. The sounds are often likened to the words " lubb, dupp," pause, " lubb-dupp." The first " lubb " sound is of low pitch and long, the second shorter, sharper, and higher pitched. The first sound is caused by the closure of the inlet valves, and possibly by the contraction of the ventricles. The second is produced by the closure of the outlet valves, and is heard better higher up in the middle of the chest.

Obviously, therefore, by listening to the heart, the condition of the valves can be judged. If they do not act properly, " murmurs," rumbling or blowing sounds, indicate a leakage.

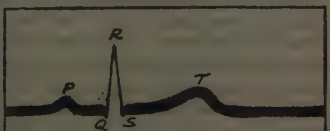


Fig. 5. Typical cardiograph.

Another method we have of examining the heart is by the device called an *electrocardiogram*. In this, the electrical currents

created by the beating heart are photographed. (A typical cardiograph is seen in Fig. 5.) This invention again has only come into use during this century and by it we are learning enormously about the heart in health and disease.

A more recent method still, is the development of ways of X-raying the heart. By this method we can learn of its size and shape (and so find out which part is diseased), and watch the heart-beat in all its details. These methods promise to teach us many surprising facts about the heart in years to come.

VARIATIONS IN THE FLOW OF BLOOD

When the heart contracts, as we saw, blood is expelled. In an average man at rest, about two ounces of blood are put out into the main artery per beat. But this amount varies enormously, and on exertion can rise to six ounces a beat. So that whereas at rest the heart might pump out about seven pints a minute, on exertion it could produce, perhaps, forty-five to fifty pints. It is amazing that we can feel nothing of this enormous rush of blood within us!

Apart from this astonishing capacity to rise to the occasion, the heart is very sensitive to changes that occur in the body around it. Yet, after all, its function is to supply the blood as required by the body as a whole. For example, when the muscles of the body contract, as on exercise, they squeeze the veins and so increase the amount of blood returning to the heart, which accordingly must pump out more. It is this increased return that makes possible the enormous increase of five times the resting output.

Temperature also affects the heart—warming quickens it, cooling slows it—thus accounting in part for the quickened rate of the heart in a fever.

HOW THE HEART IS REGULATED

But most important of all is the nervous regulation. The object of nervous regulation is to keep the heart adapted to bodily needs as a whole. In consequence there are two sets of nerves—one which slows and rests the organ, the other which prepares it for activity.

The former consists of a nerve which comes all the way from the brain, down the neck, runs through the chest giving off branches to heart and lungs and ends by supplying large areas of stomach and intestine in the abdomen. It is called the *vagus*, or wanderer.

Acting against it on the heart is the *sympathetic* nerve. The fibres of the latter come from the spinal cord in the chest region. Several of them pass into a network of nerves behind the heart, and finally, make their way to the heart muscle along the blood vessels.

When active these fibres increase the rate and strength of the heart-beat.

It may seem strange at first sight that the heart is supplied by these

two sets of nerves, vagus and sympathetic, which have directly opposite actions. But by this device a delicate regulation of the beat is obtained, just in the same way as a balance is kept level by weights put in opposite scale-pans.

For instance, the vagus tends to slow the rate of the heart. This is obviously an advantage in those who follow athletic pursuits, whether human or animal, for it gives them more reserve. For this reason athletes usually have slow, resting, pulse-rates. So do horses. If the vagus of a horse is cut the pulse-rate at once quickens, showing that a slowing down effect did come from this nerve. But rabbits have quick pulse-rates. They cannot run long distances, and if their vagus nerve is cut their pulse does not quicken any further.

Stimulation of the sympathetic nerves has the opposite effect. The pace-maker is stimulated so that the rate quickens and the size and strength of the heart-beat is increased.

STRENGTHENING THE HEART-BEAT

Now on top of the kidneys are two bodies known as the *suprarenal glands* (pron.: soo'-pra-ree'n-al). About the size of broad-beans, these glands manufacture chemical substances which are injected into the blood stream, and are thus carried to the various organs. We shall discuss their operation more fully later. But here we must note that the core, or *medulla*, of this gland secretes a chemical known as *adrenalin* (pron.: ad-ree'n-alin). This is passed into the blood, and acts in the same way as the sympathetic nerve would do. On the heart, for example, it makes the beat stronger and quicker.

If you get into a rage, nervous impulses beyond your control, since quite unconscious, pass down the sympathetic nerves. Some go straight to the heart, others go to the suprarenal glands, which immediately pour out large quantities of adrenalin. This, amongst many other actions, affects the heart, making it beat more powerful and quickly—a process which results in " palpitation " so typical of anger or fear.

SLOWING DOWN THE HEART-BEAT

Should the heart put out too much blood into the aorta, then this great vessel is stretched; this stimulates the endings of the vagus nerve which lie in the walls of this artery. Messages pass up at once to the brain that too much force is being put on to the aorta. Quickly more messages are relayed down to the pace-maker, which slows the heart-rate, and to the heart muscle, which contracts less forcibly—both mechanisms by which the strain is taken off the stretched walls of the artery, so that all is well once more.

This is an example of how the delicate balance is always kept. Many reflexes of this nature govern every heart-beat so that the quantity of blood pumped out shall be just right.

Recently another centre of this type of reflex has been found in the neck—the *carotid sinus*. If blood within the *carotid*, or neck, artery stretches this portion of the vessel, a reflex is immediately set up and a message is sent down to the heart to reduce the pressure which is effected by slowing up the rate of beat.

THE PULSE AND ITS RATE

The pulse-rate in human beings is as we noted, usually taken as being about seventy-two per minute. But it is a rule of Nature that the smaller the animal the higher the pulse-rate. Mice have very rapid pulse-rates and new-born babies have a rate of about one hundred and thirty. As the body grows the rate slows down. At the age of five years for example, a child's pulse has dropped to ninety, and about the age of fifteen, it becomes the adult rate of seventy. Conversely, elephants have slow pulse-rates.

Even in humans there is great variation. Napoleon was supposed to have a pulse-rate of only about fifty—but he was abnormal in many ways physiologically, as well as in his psychology.

Commonly it is found that in children taking a deep breath, the pulse is quickened, while breathing out slows it down. This is quite normal and is the result of the fact that one of those regulating reflexes already mentioned, has not yet become quite perfectly balanced. As the child develops, so this effect disappears, for the mechanism is growing up, too.

SUPPLYING THE HEART WITH BLOOD

But there is one vital question which, in our discussion of the heart, we have so far left out. How does the heart muscle get its own blood supply? For after all, this muscle does an enormous amount of work in pumping the blood to other organs; and it, therefore, needs blood itself. In frogs, the walls of the ventricles are porous like a sponge, and sufficient blood is soaked up, so to speak, for this purpose. But this would not do in mammals. In the heart of man, therefore, there are two special vessels called the *coronary* (pron.: cor'-own-ary) arteries which supply the heart muscles.

These two arteries (as can be seen in Fig. 3), arise just above the aortic valve, so that they take first pick of the blood pumped out by the heart. From here they run round the heart, forming a ring like a crown (compare the words "coronary" and "coronation"). Upon these small arteries which nourish the heart then, life depends. If they get blocked then the heart muscle dies and the heart stops.

Incidentally, these arteries were also drawn in anatomical sketches by Leonardo da Vinci—but it was Harvey, again, who suggested to the world their real function. In the seventeenth century, Vieussens, discovered small holes leading from the cavity of the left ventricle into the heart wall—these are all that remain in humans

of the primitive frog's method of nourishing the heart muscle.

Now that we have glanced at the heart we must consider the blood vessels which carry the blood to and from the tissues.

From the heart, blood passes into the great aorta—the main artery of the body. This vessel (as will be seen in Fig. 7) arches upwards, turning backwards, and to the left, at the level of the second rib. As it runs backwards, it passes to the left of the wind-pipe and gullet, until it touches the spine. Here it turns down and runs alongside the vertebral column, to pass through the diaphragm into the abdomen. Its general course (Figs. 8 and 9), is very like the crook of a walking-stick.

It is from the arch that all the main blood vessels to head and arms branch off.

This unsymmetrical sweep of the aorta to the left is the result of development from a primitive pattern, which may be seen in fishes, where arches on both right and left are seen. But in mammals only the left arch persists.

As we have noted the main artery to the head is the carotid. About the middle of the neck (Fig. 6), this divides into internal and external branches. Just above this is a small dilatation —the carotid sinus, the importance of which we have noted. The internal carotid runs up to enter a hole in the skull to supply the brain. The external carotid supplies branches to the face, scalp and tongue. The course of these arteries can more clearly be followed in Fig. 6. The vertebral artery can also be seen wending its way through the cervical vertebræ to reach the inside of the skull. Here its branches join with branches from the internal carotid to form a ring of arteries,

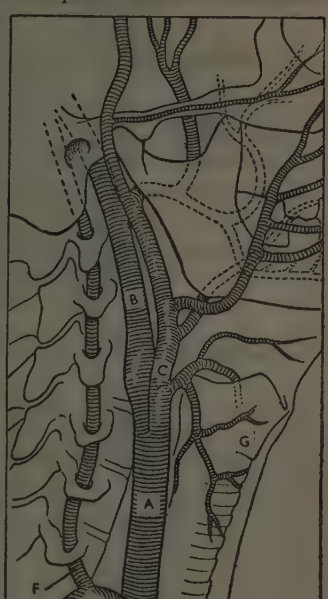


Fig. 6. *Blood vessels of throat and neck.* (a) *Common carotid artery.* (b) *Internal carotid artery.* (c) *External carotid artery and branches.* (d) *Subclavian artery.* (e) *Innominate artery.* (f) *Vertebral artery.* (g) *Thyroid cartilage.*

the " circle of Willis," from which branches penetrate deep into th brain substance, and also course along its surface.

The main trunk of the vertebral artery passes below the clavicl or collar-bone (whence it is known as the *subclavian* artery), becomin the *axillary* artery (Fig. 7). This runs across the arm-pit, giving o various branches to the chest wall in the neighbourhood. Soon becomes the *brachial* artery, which can be felt beating on the inne

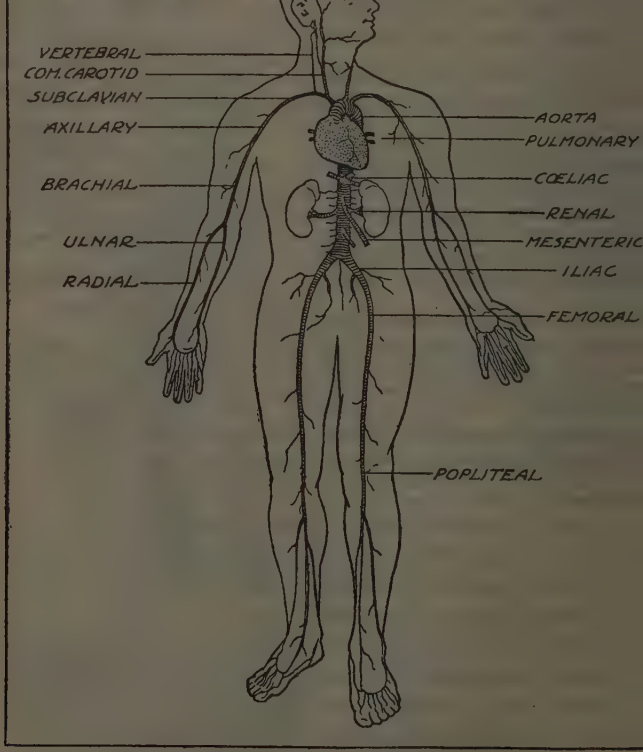


Fig. 7. The principal arteries of the body.

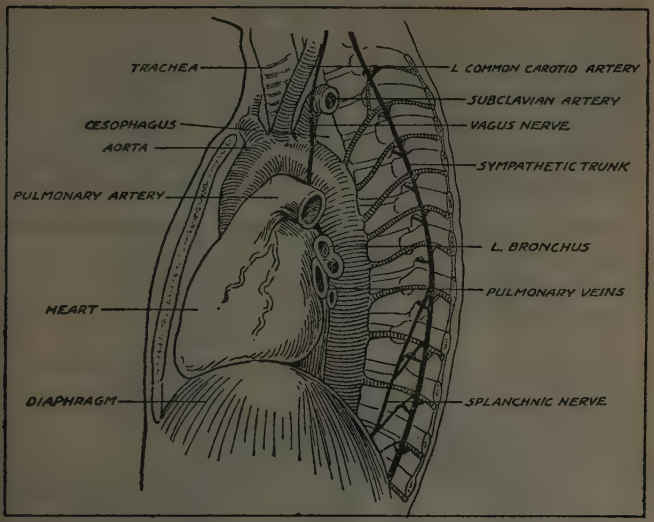


Fig. 8. *Cross section of the chest (with the left lung removed) showing the position of the heart and the principal arteries and nerves.*

side of the upper arm. At the elbow this divides into two, the *radial* and ulnar arteries. The former of these runs along the thumb side of the arm to the wrist, where it can be felt beating at the place where the pulse is felt. After that, it winds to the back of the wrist and hand, to disappear deep into the muscles. The latter runs down the other side of the arm to the hand, disappearing into the muscles of the palm amongst which it joins the end of the radial artery.

From the aorta, as it runs down in the chest, rise the intercostal arteries, which run round the chest, in the spaces between the ribs, to the breast-bone, in front. Other branches go to the pericardium or heart sheath, to the smaller air tubes of the lung (known as *bronchi*), and to the gullet. These relations are well illustrated in Fig. 8, which shows a chest opened from the left side with the lung removed. Below the arch of the aorta, is seen the left pulmonary artery. Below this again is the left bronchus.

As the intercostal arteries run sideways, they are crossed by a nerve running from top to bottom of the chest. This is the sympathetic trunk already mentioned, and is formed by the outflow of fibres from the spinal cord through the gaps between the vertebræ. A branch into the abdomen is the *splanchnic* (pron.: splank-nik) nerve.

Piercing the diaphragm, the aorta now reaches the abdomen (Fig. 9). Here it gives off many important arteries as it descends in front of the spine until finally, it divides into two. These two branches are called the *iliac* arteries. Before it divides, however, it gives off a number of branches, the most important of which are those leading to the viscera. The first, the *cœliac* artery, supplies the stomach, liver, and spleen; next comes the *superior mesenteric* artery, which supplies the whole of the small intestine and part of the colon or large gut. The *inferior mesenteric* artery rises about an

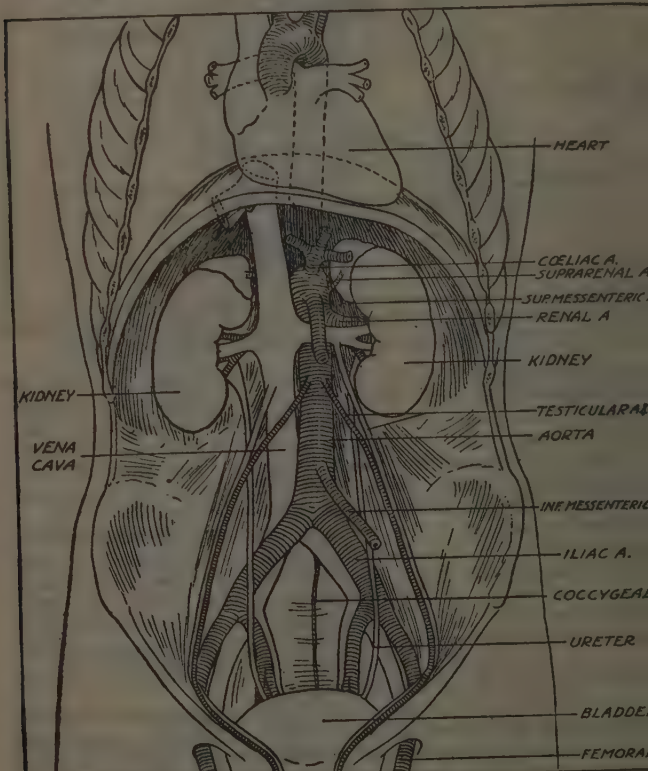


Fig. 9. The chief blood vessels of the abdomen.

inch the point where the aorta divides, and supplies the bowel.

Two small suprarenal arteries arise one on each side of the aorta and lead direct to the suprarenal glands which are of such vital importance as we saw, in the regulation of the flow of blood. Amongst the other branches which the aorta gives off are the *renal* arteries to the kidneys —very large vessels considering the size of the kidneys. They rise just below the superior mesenteric artery. The testicular arteries, long, thin vessels, run a long course through the muscles of the abdominal wall, down to the testicles. In the female, the corresponding ovarian arteries have a shorter journey.

From the aorta come also small arteries for the supply of the under surface of the diaphragm and the muscles of the back. Finally the middle sacral artery is a small branch that really continues the line of the aorta, carrying blood down along the sacrum to the vestige of what was once man's tail.

BRANCHES OF THE CHIEF ARTERY

The two common iliac arteries into which the aorta divides pass sideways, and each soon splits into branches called external and internal. The internal iliac artery is the remains of that which supplied the unborn babe with blood from the mother. It passed along the umbilical cord to the wall of the mother's womb. All this part atrophies after birth, and becomes in the adult, only a solid, bloodless cord. This artery, known as the *hypogastric*, also gives off branches chiefly to the bladder and uterus.

The external iliac artery (Fig. 7) runs down to enter the leg on the inner side of the thigh, where it can be felt beating. Here it becomes the *femoral* (pron.: fe'm-oral) artery, which after giving off branches to the muscles of the lower abdomen and thigh, passes down the front and inner side of the thigh in a funnel-shaped canal, formed by a series of muscles and fibres in the thigh (known as "Hunter's canal," after the great London surgeon), and winds gradually backwards until at the knee it is behind the joint in the area known as the *popliteal* space, whence it is known as the *popliteal* artery.

This short artery gives off branches to the knee-joint and soon divides in the lower leg into two other arteries. The first of these runs down supplying the muscles of the leg to the foot, where it becomes the *dorsalis pedis* artery, which can be felt by placing a finger in front of the ankle midway between the two knobs on each side. This artery which supplies the muscles and tendons of the foot, pierces between the bones to come out on the sole of the foot. The other branch of the popliteal artery runs down the back of the leg to the inner side of the ankle.

The veins of the body run with the arteries for the most part, and have corresponding names. But the main vein from the neck and head is called the internal jugular. This joins up with the subclavian

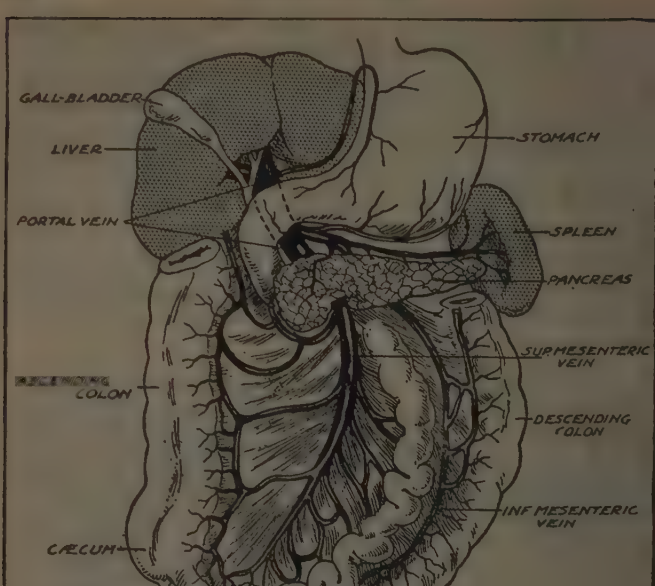


Fig. 10. *The portal system of veins.*

veins from each arm to form the superior vena cava which, as we saw, runs into the right auricle of the heart.

The main veins from the leg join up just to the right of the main split in the aorta, to form the inferior vena cava which, passing up in front of the spine, beside the aorta, pierces the diaphragm and enters the right auricle of the heart.

A special set of veins called the *portal* system is situated in the abdomen (Fig. 10). This system consists of all the veins that drain blood from the digestive organs—from stomach right down to rectum—as well as from the spleen, pancreas and gall-bladder.

We saw that blood was sent to those parts by special arteries and this blood absorbs nourishment from the gut. From there it carries its food burdens back to the liver, where they are first treated—a

process which we shall discuss more extensively in a later chapter.

The portal system, then, includes the veins from gut and spleen, etc., which form the portal veins running up to the liver, where they split into small branches like capillaries. This process enables the blood to come into intimate contact with the liver cells. After leaving them, it is collected into another set of veins that enter the inferior vena cava, just before it reaches the right auricle.

HOW BLOOD PRESSURE IS MEASURED

Blood travels from arteries to veins. If you cut an artery, blood spurts out of the end in jets as the heart beats. Along this path, however, the pressure that drives the blood must be diminishing.

In 1732, Hales inserted a " brass pipe " into the artery of the leg of a mare and noted the height to which the blood rose in this tube—eight feet three inches. This was the first known measurement of blood pressure. Nowadays a cuff is put round the arm and blown up with air. The pressure is noted at which the pulse fails to pass the cuff, for this just compresses the artery and is therefore just equal to the pressure the blood is exerting from within. It is fortunate that Hales's rather drastic method has been improved upon, but this does not detract from the brilliance of his original idea, without which we might never have realized the importance of blood pressure.

The height of the blood pressure varies remarkably in different individuals; it is chiefly determined by the force with which the heart expels the blood, and the resistance from the muscular walls of the small arteries. This process is found for example, in an artery like that in the upper arm—the brachial artery; but as the vessels branch and become smaller, the pressure falls until in the capillaries of the skin, it is equivalent to only a minute fraction of what it was in the arteries.

REGULATING BLOOD PRESSURE

Now arteries and veins are different in their structure as you see in Fig. 2. The sturdy muscles in the wall of the artery are lacking in the thin wall of the vein. Note, however, that both are lined with a smooth substance known as *endothelium*. The heart, as we saw at the beginning of the chapter, is like a pump inserted into an elastic ring of tubes. There are therefore all kinds of factors to be considered in the regulation of blood pressure: the amount of blood flowing to a given part of the body, the amount of blood put out by the heart, the resistance of the muscular arteries, whether they contract down or dilate up, and other things. We cannot describe all these complexities here, but we may note that blood is taken from the veins and passed by the heart into the arteries (Fig. 11). Notice the large network in the figure, between artery and vein.

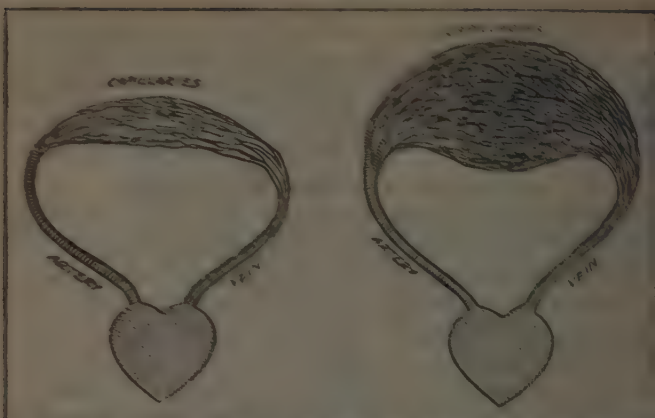


Fig. 11. The relation of the capillaries to the blood circulation.

This represents the capillaries, of which there are enormous numbers in the skin, inside the abdomen, in fact, all over the body. Now if for some reason these dilate, like the network in the right-hand figure, then they may contain a large part of all the blood in the body. In consequence the heart receives very little blood from the veins and cannot, therefore, keep up a good circulation.

The brain is the first to be affected by this lack of blood, and consciousness is rapidly lost. This kind of thing happens in accidents, and is known as "shock." It happens of course also if bleeding goes on for a long time—if the brain is deprived of blood for more than a few seconds unconsciousness always results. Common "faints" are often due to nervous upsets whereby the vagus nerves get the upper hand, thus causing a slowing down of the heart and greatly diminishing the outflow of blood. The brain is deprived of its blood, and the person faints.

Probably every one has felt the pulse at his wrist sometime or other. This is not the only place it can be felt, a finger on the side of the head just in front of the ear will feel it. Even in the foot, on the inner sides of the thighs, and in the neck very easily—in all these places arteries are pulsating near the surface and may be felt. But the farther we go from the heart the less strong is the pulsation.

What is the pulse? If blood flowed evenly from heart to limbs and organs there would be no pulse, but as the ventricle contracts it throws out a large quantity of blood into the aorta, which is an elastic tube. This stretches and then rebounds again, being elastic, but

as it rebounds it cannot send the column of blood back into the heart, as the heart's outlet valves have closed. The blood, which must go somewhere, is therefore pumped off on its long journey along the arteries. The wave of stretch and rebound travels rapidly right along the arteries, until it reaches parts where we feel it as the pulse. This wave travels at the rate of about seven metres per second, so that the pulse in the wrist occurs about one-fifth of a second later than the heart-beat.

The pulse wave is due essentially to the elasticity of the aorta, not to the contraction of the ventricle, and it is possible for the ventricle to contract without producing a pulse at the wrist, if it puts out so little blood as to fail to expand the aorta. This does happen with small premature contractions—the heart-beat can be heard with the stethoscope, but no pulse results from it. Consequently the next beat of the heart is a good big one to make up for it, and as such is often felt as a "palpitation."

THE CAPILLARIES OF THE BODY

In the previous chapter we noted how important was the circulation through the capillaries of the skin, in regulating temperature and in the health of the skin. These microscopic vessels exist, however, in all the organs of the body, those in the skin being most easily studied. If a strong light is directed at the edge of a finger-nail, whilst a microscope is focused on the part, the capillaries can actually be seen. The thin wall, one cell deep only, composed of flattened cells, has on its outside occasional long spidery cells which can draw in their spidery processes, and in this way contract the capillary. These are known as *Rouget* cells.

Through these narrow channels red blood cells may be seen wandering. Sometimes the space is so narrow that to round a corner the red blood cell is squeezed out of shape. Through the thin wall of the capillary, nourishing fluid diffuses out towards the cells near by.

HOW ORGANS ARE SUPPLIED WITH BLOOD

The most important feature of the capillary circulation is its variability. At rest the greater number of capillaries are closed, but on activity they at once open up in order to bring more blood to the active organ. In a muscle for example the capacity of the capillaries may be multiplied over seven hundred times during hard exercise.

Veins take the blood from capillaries back to the heart. How small is the pressure of blood in veins is evident on cutting one. Whereas a cut artery spurts, a vein simply produces a slow ooze from the end farthest from the heart. Blood in the veins, particularly in those of the legs, is propelled towards the heart by muscular action,

and by the sucking action of breathing. It is because the movement of leg muscles is so important in the return of blood that one finds it uncomfortable to stand quite still for any length of time, and let the blood in the leg veins stagnate.

DIVIDING UP THE BLOOD SUPPLY

We are now in a position to try to appreciate the nature of the problem that faces Nature, the problem of the regulation of the blood supply to any particular organ. Obviously, at one time the stomach, for example, needs a relatively large supply to enable it to perform its function of digesting food: another time not the stomach, but the muscles of the leg are in need. Since there is only a limited amount of blood to go round, it is necessary in such a case, to shut off the circulation to the stomach and all other inactive organs, and turn it on to the newly active leg muscles.

We have already given a hint of one of the main devices Nature uses in doing this, when we discussed the regulation of blood pressure by the aid of the two special nerves called the sympathetic and vagus. These nerves are again used; as also, to a less extent, is a more primitive local chemical action on the blood vessels.

In the primitive part of the brain between the spinal cord below and the mid-brain above, is a part called the *medulla oblongata*. From this point arise the vagus nerve and many of the nerves to the face. In this area of the brain is also a collection of nerve cells known as the *vasomotor* centre. These cells, as their name implies, form a central control, by which the various blood vessels of the body are regulated. From this centre run out two sets of nerves whose branches reach to nearly every small artery of the body.

NERVES THAT CONTROL THE FLOW OF BLOOD

One system is the sympathetic set of nerve fibres we already know. These, when stimulated, contract all the small blood vessels, and so raise the blood pressure—with the exception of the blood vessels in the lung and heart (coronaries). The other system flows out along with the spinal nerves and when stimulated, dilates these same arteries.

In fact, just as the heart is controlled, as regards its output, by a reflex action, so are the blood vessels controlled from the vasomotor centre. Stimuli from all over the body may reach this centre and modify the nice balance, which it usually holds between constriction and dilatation of the arteries. Even stimuli from the brain—emotions and thoughts, not to mention pain—have this effect. It is for this reason one may faint with pain or fright. The brain sends down forcible messages to the centre which becomes disordered, so that the vessels of the abdomen, for example, are dilated, and thus draw blood from the brain. Loss of consciousness results.

One would have thought that when standing quite upright the pressure of blood in the arteries of the leg would have been greater than that, say, in those of the neck. For the latter are above the heart, the former below it; they should therefore, be affected by gravity. But such is the delicate regulation of the vasomotor centre that the pressure in both sets of blood vessels is exactly the same.

When one has been ill, this nice adjustment of the vasomotor centre is often lost for a time, and on standing up for the first occasion after a long stay in bed, the centre does not at once stop the tendency of the blood to drain down into abdomen and legs. Because of this drain the brain is starved of blood and the patient totters, feels dizzy and sometimes faints.

CHEMICAL CONTROL OF THE CIRCULATION

But apart from this marvellous nervous regulation of the distribution of blood, there is also a chemical mechanism working. For instance, very dilute acid causes small blood vessels to dilate. When muscles work they produce a lot of lactic acid and carbonic acid. These produce dilatation of the vessels in their neighbourhood, so improving the circulation to the active muscle automatically.

There are also chemical mechanisms involving the glands. We saw before, how adrenalin from the suprarenal glands imitates the action of the sympathetic nervous system, and so prepares the body for muscular activity of the nature of "fight or flight," sending up blood pressure and diverting the blood to the muscles, and away from the skin and intestines.

There is also a secretion from another gland, the *pituitary* (pron.: pit-yoo'-itary), situated inside the skull, which constricts small blood vessels, so tending to raise blood pressure.

With all these factors to be taken into consideration, it will be readily understood what a complex thing is the regulation of blood flow to any particular organ, and the blood pressure level in any individual.

GIVING THE BLOOD OXYGEN

The lungs hold a special relation to the circulation, as we saw at the beginning of the chapter, and this raises particular points which we must grasp, to understand the pulmonary circulation.

We saw that the right ventricle which supplies the lungs is much less massive than the left. This is because the pulmonary circulation is shorter and resistance to the flow of blood much less.

The short pulmonary artery divides into two, each going to one side to its respective lung. Quickly the artery branches into smaller and smaller arteries until an enormous bed of capillaries is formed, which is separated only by one layer of cells in the lung, from the air. Here the red blood cells unload carbon dioxide and take up

oxygen, before passing on into the pulmonary veins, and so back t the heart. As each breath is taken in and the lungs expand, th field of capillaries is increased so that more room for blood is mad On breathing out, the reverse happens.

THE BRAIN'S BLOOD SUPPLY

The brain also has a peculiar relation to the circulation. plentiful supply of blood is brought to the brain by the two intern carotid arteries, and the vertebral arteries, which we saw windin their way through the holes in the vertebræ of the neck. The out layer of grey matter which covers the surface of the brain and is th site of the higher functions, is supplied also from blood vessels on i surface. Brain is, as we have seen, very sensitive to any tempora deprivation of its blood supply—due to its great need of oxygen though strangely enough when at work it uses very little of this vit substance.

The circulation here is, however, profoundly affected by the fa that the brain is lodged in a rigid box, the cranium, so that a increase in the volume of matter, whether brain or blood inside th box, will either increase the pressure within very rapidly or dri something out of the box, if the pressure is to remain constan In consequence, when the heart beats and blood is pumped into th cranium, the large veins running from the brain to join the jugul veins of the neck, are compressed. A further increase of pressu results in expulsion of the special fluid cushion—the cerebro-spin fluid—that protects the brain from its hard container.

If a hole is made in the skull, brain will bulge out of it owing the pressure pushing from inside, much in the same way as the inn tube of a bicycle tyre tends to bulge out of a hole in a worn cove Through such a window the blood vessels on the surface of the bra have been observed. When the sympathetic nerve in the neck stimulated the sheet of vessels over the surface of the brain, contract and the same happens when adrenalin is injected.

WHAT WE MEAN BY "IN TRAINING"

It is interesting at this point, to consider exactly what we mea when we say that we are in or out of "training." The traine athlete is a man who has by long practice achieved the maximu of efficiency in his muscles. The response to a call for effort is measure of muscular efficiency. For example, over a reasonab period of time, a trained man can increase the amount of muscul work, and the rate of blood circulation, by as much as six times th resting values. For a short burst of energy, as in a hundred yard sprint, much more energy is available, as a special mechanism burning fuel without oxygen can be used, creating what is known an "oxygen debt," which is paid off after the exercise is ove

The difference, then, between the trained and the untrained man es in the amount of energy in reserve. The untrained man has to uicken the heart-beat to obtain a certain increased flow of blood, ne trained one does it by virtue of larger heart-beats with no increase f heart-rate, and so on. Pulse-rate, therefore, rate of rise, and articularly, time taken to return to normal after exercise, is a very ood criterion of training.

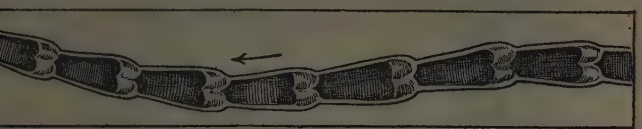


Fig. 12. *Longitudinal section of a lymphatic* (*greatly enlarged*).

Blood brings nourishment to the cells. But blood, as such, is onfined to the inside of blood vessels and cannot, therefore, come into irect contact with the tissues it is feeding. To do this, there must e a " middleman " who fetches and carries between cell on the one and, and capillary on the other. This middleman is the *lymph*. ymph is a fluid that fills up the spaces between the cells. From these paces there is developed a lining of flat cells, just like the lining of he valved blood vessels, which join together to form a small valved essel, known as a *lymphatic* (Fig. 12).

These lymphatics take away fluid from the tissue cells when it is xcessive. They run along with arteries and veins, usually forming a ide network, towards the centre of the body. On their way they ay pass through special filters called lymphatic glands, which lie n groups scattered all over the body, but particularly in the arm-pit Fig. 13), groin, neck, inside the chest and abdomen, and along the ront of the spine.

This whole system forms a primitive kind of fluid circulation, and

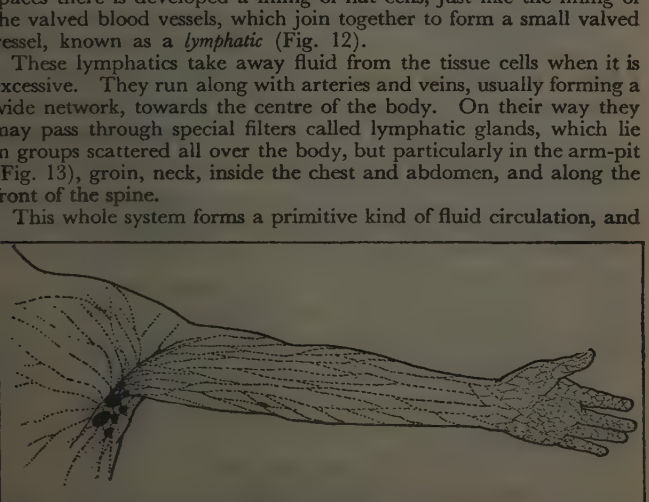


Fig. 13. *The superficial lymph glands and lymphatic vessels of the arm.*

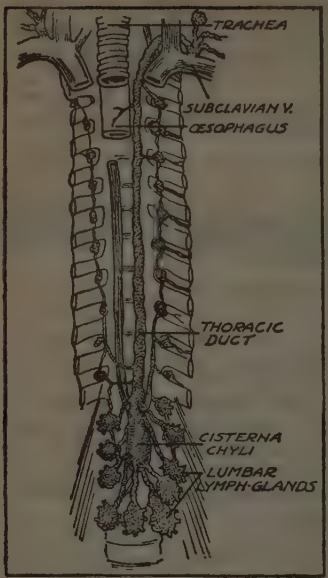


Fig. 14. *The thoracic duct.*

in the frog there are contracting muscular sacs like hearts, to keep up the lymph flow. The lymphatics form a big main channel, called the *thoracic duct*. This commences in the abdomen, being formed by the lymphatics from the legs and abdomen, and running up through the diaphragm to the chest, collects other lymphatics, until nearly all in the body have run into it. Having received the lymphatic drainage from the left side of the head and left arm, it turns and opens into the junction of the left jugular and subclavian veins, so passing its contents back into the blood stream (Fig. 14). The right arm and right side of the head drain into the right jugular vein.

Fat is absorbed from the intestines by these lymph vessels, which may be seen like milky streaks filled with fatty material after a meal. Along the thoracic duct, this fat enters the blood in the neck, as mentioned. But usually lymph fluid is very similar to the fluid part of blood—the *plasma*.

Lymph, after all, is formed from this blood plasma which exudes through the walls of capillaries, carrying precious burdens of oxygen and food for the cells; among the latter it takes up their unwanted products and passes these back to the blood.

If the capillary wall is leaky for some reason, such as injury, disease, or abnormal blood plasma within it, then fluid collects in the tissue spaces. So much may collect that on pressing firmly with the finger, a large dent is left which only slowly fills up. This is known as *pitting*, and is a sign of the disease known as *œdema* or "dropsy." Dropsy of course tends to form in the feet, merely as the result of gravity acting on the fluids of the body. It is usually a sign of poor circulation.

If one were to inject a coloured dye under the skin, the particles of dye would, in time, be seen going along the lymphatics and so mapping out their course. The very same thing happens with bacteria. If they invade under the skin sometimes one sees red angry

streaks running up the limb, indicating that the lymphatic is acutely inflamed, and that the bacteria are spreading rapidly, so that there is a risk of them getting into the blood.

But here the lymph glands come in, for they bar the way to the blood stream. In a lymph gland are packed millions of small, round cells, called *lymphocytes* (pron.: lim-fo-sites), which we shall meet again in the blood. Here the bacteria are filtered out and dealt with. It is because of this lymph-gland action that after a dirty cut on the hand, you may feel a tender swelling in the arm-pit.

CHAPTER VI

THE STREAM OF LIFE

INSIDE the closed system of tubes, composed of heart and blood vessels, is the blood—the only fluid tissue of the body. For blood is as much a tissue as cartilage or muscle; the only difference is that the substance between the individual blood cells, instead of being solid, as is well shown in the microscopic picture of cartilage, consists of the fluid known as plasma.

The human body is faced with the problem that organs such as liver and kidneys are quite incapable of existing on their own, apart from the body. This is one of the penalties of specialization. They can exist only when working together in harmony inside the body. So that we have not only to analyse the separate parts and functions of an organ, but try and see how it fits in with the others, so helping to form the real unit which is the body as a whole.

The blood is the great integrator of the body. To "integrate" means to make harmonious relations of fractions, so that a new unit is produced. (For example, if you add the fraction two-fifths to the fraction three-fifths, the result is one harmonious whole, a new unit.) In the human body the organs are the fractions—the human being as we know him in his daily life, is the new unit.

The blood makes this step from one to the other possible—and so is the integrator. It carries out this process of integration by virtue of its being mobile, and flowing continuously round the body, coming into contact with all the organs, thus unifying, for example, food supply, the disposal of waste products and chemical messages. All organs share its benefits.

Integration is perhaps rather a difficult conception, but it is of vital importance to the understanding of the human body. Two systems—the blood and the nervous system are, in their different ways, devoted very largely to this function.

We hear a lot of discussion nowadays of *analysis* from psychological to chemical. Analysis means to take to pieces or to

dissect into component parts. This is the opposite and easier process to *synthesis*, which means to build up. To build into a unit is to integrate—an amplification of synthesis. For example, one may take a watch and in an analytical frame of mind, take it to pieces to find out how it works. Now what is the difference between the watch you started with, and the pile of wheels and springs you have on the table before you? The only difference is one of integration, for you do not need to add a single bit of material; you only need to put these parts together in the right relation to one another (and there lies the rub) in order to make a watch again.

In exactly the same way, the human body is not just composed haphazardly of brain, liver, heart and kidneys, etc.—for there is something more to it. These organs have peculiar relations to one another, mechanically, chemically, and in other ways, and it is a result of these special relations that the whole human being is produced with his human attributes, both physical and mental.

But it takes perhaps minutes for blood to link up two different parts of the body, so a more rapid integrator must be found. This we have already seen at work in the regulation of the heart—the sympathetic and vagus nerves. Even more rapid is the central nervous system which we shall discuss later.

WHY IS BLOOD RED?

Blood in mammals is red. Why? It is blue in lobsters—so red is not the only possible colour! Even in humans the shade of red varies. The arteries spout out a bright red blood—the veins ooze a darker almost purple shade. Through the skin veins look blue. We speak of "blue blood in his veins" referring to a person's aristocratic birth. The blueness which may have given rise to the phrase was probably not due to any difference in the actual colour of aristocratic blood from that of less fortunate folk, but to the thinner, more delicate aristocratic skin between vein and air. This delicacy of skin made the vein more visible and emphasizes its blue tinge.

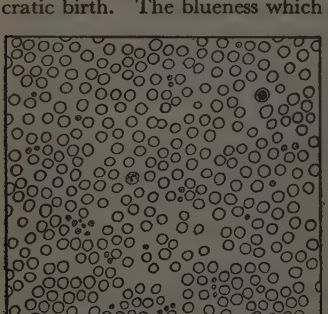


Fig. 1. *A typical "field" of blood cells as seen under the microscope.*

If blood is looked at under the microscope, it is at once seen to consist of myriads of cells, known as *corpuscles*, mixed in the fluid medium plasma (Fig. 1). The cells are of different kinds, red—hence the colour of blood as a whole; white; and small bodies

known as *platelets*—about which discussion still continues as to whether they are worthy of the name "cell" or not.

If blood is collected into a glass jar and left, in a few minutes it turns quite solid, or clots, so that the jar could be turned upside down without spilling it. As it clots fluid rises to the surface and this fluid is called *serum*.

HOW MUCH BLOOD HAVE WE?

About five per cent of the weight of the body is blood—if one is fat, less. That is, if the weight is ten stone, about seven pounds of it is blood. The earliest experiments to find out the amount of blood in the body were done by draining hanged criminals of their blood by opening the jugular veins. This method was, though ingenious, inaccurate, for some of the blood cannot drain away however the body is tipped. The inaccuracy was overcome by adding to this the amount obtained from washing out the vessels with salt solution and then mincing the body up thoroughly. Fortunately, these early heroic methods have now been improved upon. A quite effective modern way is a simple injection of a dye into the blood. After a certain length of time a sample of the dyed blood is taken and compared with a sample of standard colour. The amount the dye has been diluted can be gauged with accuracy and this gives a very good estimate of the total amount of blood in the body.

In man, about forty to fifty per cent of blood is solid corpuscles, and fifty to sixty per cent is composed of fluid plasma. In dogs corpuscles are relatively much fewer.

COUNTING BLOOD CORPUSCLES

These corpuscles may be counted—an investigation very commonly carried out by doctors. By simply pricking the finger with a needle a drop of blood is obtained. A measured amount is then sucked up into a little pipette. This amount is diluted a hundred times so that the cells shall not be too numerous to be counted separately. Then a drop of the mixture is run on to a very special microscope slide, which is ruled in squares of known size. From the number of red blood cells per square, the number in one cubic millimetre of blood is calculated. In healthy people this is about five millions. But in some severe forms of anæmia the figure may sink to as low as a million.

A normal blood count would be :—

Red corpuscles ..	5,000,000
White corpuscles ..	8,000
Platelets, about ..	300,000

In the whole body, therefore, there are about thirty million million red blood corpuscles, and fifty million white.

These red corpuscles are of importance, very largely because they

carry a red dye or pigment known as *hæmoglobin* (pron. : hee'mo-globin). This pigment is most important for it is the carrier of oxygen from lungs to tissues. It is measured by taking up a measured drop of blood, as was done for the blood count, and putting it in a little tube where it is treated with coal gas, the carbon monoxide of which alters the hæmoglobin. Water is then added until the colour is the same as that of a special standard. If water has to be added in the tube up to the one hundred mark until the colour is the same as the standard, then the hæmoglobin is said to be one hundred per cent, which is normal. But if there is a shortage of this precious pigment, then it will become the same as the standard perhaps, when only the fifty or sixty mark is reached. In this case the hæmoglobin is said to be fifty or sixty per cent—and the patient is anæmic.

HOW OXYGEN SUPPLY AFFECTS THE BLOOD

Now the amount of oxygen that the blood can take up is dependent on the amount of hæmoglobin in it—so that a person with only fifty per cent, or half, the normal hæmoglobin is obviously going to suffer from lack of oxygen, just as much as if you halved the amount present in the air he breathed. So it is that an anæmic person pants, and breathes in and out more quickly than normal, in order to try to take up in two breaths what he should have been able to take up in one. So he is obviously at a disadvantage if any exertion has to be undertaken, and many tissues too do not get their full supply of oxygen. The brain, in consequence, sends down sensations of fatigue (its method of complaint), the heart palpitates, shortness of breath develops, the muscles tire, and the appetite fails because the stomach cannot do its work properly. Symptoms, or sensations, of discomfort multiply in one who is anæmic.

BLOOD TRANSFUSIONS

The red corpuscles of blood are very sensitive to the plasma or serum in which they are bathed. In the body they float about freely in the surrounding plasma. But if human red blood corpuscles are put into a drop of serum from a horse, for example, they run together into clumps and stick together. This process is called *agglutination* and is of great practical importance in the administration of blood transfusions. For if the serum of the patient agglutinates the red corpuscles of the blood donor, it will probably destroy them, in doing which, the patient will be made very ill—even worse than he was before. For this reason, human beings are tested before their blood is taken for a transfusion.

It has been found that there are four different classes, or groups, of people, according to these tests. This agglutination is actually

due to substances in the corpuscles called *agglutinogens* reacting with substances in the plasma of the patient called *agglutinins*. These agglutinogens are of two main kinds, which have received labels, A and B, and they react with corresponding agglutinins, " a " and " b," in plasma.

Now any particular person may have in his blood either agglutinogen, A or B, or neither (0). A similar statement applies to the serum and agglutinins, " a," " b " and " 0."

THE FOUR GROUPS OF BLOOD

So there are four groups of bloods—A corpuscles in " b " serum, B corpuscles in " a " serum, A B corpuscles with " 0 " serum (no agglutins), and 0 corpuscles with " a b " serum. Note that the serum and corpuscles cannot both contain A and " a," for then they would agglutinate in the body. Group " 0 " corpuscles, since they contain no agglutinogens, cannot agglutinate in any plasma. People in this group are therefore called " universal donors." Similarly, people with serum of group " 0 " cannot agglutinate anybody's corpuscles, and so can take blood from any group. They are " universal recipients." About forty per cent of English people are said to belong to the universal donor group.

Since any of us may some day be called upon to give blood for a transfusion, it is important to understand this rather complex matter of " grouping " which the doctor has to go through before deciding if one is suitable or not. This he does by mixing prepared serum of a known group with a drop of your blood on a white plate, and watching for agglutination.

Blood groups have another kind of interest in that they are inherited from one generation to another; they act as the Mendelian dominant characteristics (described in Chapter II, page 49). For this reason, blood grouping is sometimes carried out in medico-legal cases where there is dispute as to the parents of a child, and sometimes gives a decisive answer—though not by any means always, however.

WHY BLOOD MUST BE ALKALINE

One of the most important properties of blood is its reaction—is it acid or alkaline? The difference between an acid and an alkali is a problem of chemistry. Suffice it to say here that water is neutral and is therefore neither one nor the other. Some everyday examples of *acids* are vinegar (in which acetic acid is present) and sulphuric acid, the burning " vitriol " used by criminals. When dissolved, these acids liberate small particles of electricity known as *ions*—in these cases, H or hydrogen ions. *Alkalis*, such as caustic soda, in solution liberate OH or *hydroxyl* ions, of opposite electrical nature.

Blood is just on the alkaline side of neutrality, and it is of vital

importance to the tissues that it should remain so, and not change its reaction to acid or even to more alkali, for if this happened, the tissues would very soon die.

In actual fact, a very ingenious method of so-called " buffers " exists, so that in spite of blood being only just on the alkaline side of neutrality, a considerably larger amount of acid than one might have expected must be added to change its reaction at all. This is largely due to a plentiful supply of sodium bicarbonate in the blood —which takes up acid with very little change of reaction, in that very few free hydrogen ions are liberated.

This property of stability, where acid and alkali are concerned, is of the first importance to the body, because the slightest change to the acid side at once stimulates the nervous centre governing breathing. Also, cells in their activities are always releasing relatively large quantities of acids—so that their quick neutralization by blood alkali is imperative for the body's safety.

THE NATURE OF PLASMA

We saw above that blood consisted of two different portions, the solid red corpuscles floating in a fluid medium, the plasma. This plasma is the substance in which foods are dissolved and carried to various parts of the body, and is therefore of great importance. Plasma contains the substance which makes blood clot. Inside the body, where clotting does not occur, this substance flows in the blood as *fibrinogen*. When blood is shed, the fibrinogen is turned into fibrin, which forms wavy threads and so makes clots.

If a jar of blood is left, it will clot and in time the fibrin threads contract, so that the clot shrinks. When this happens, the fluid remaining is squeezed out, like water out of a sponge, and collects on top. This fluid is blood serum. So blood plasma, by clotting, is turned into fibrin and serum—or, in other words, serum is simply blood plasma minus fibrin. Blood serum contains about ten per cent solids in it in the form of blood proteins and salts, the chief of which is " common salt " or sodium chloride. There are also very small amounts of sugar, fatty substances, and a chemical known as urea (being taken away to be excreted by the kidneys). The fats and sugar are usually increased after a meal, for they are absorbed from the gut into the blood plasma. The blood proteins are two, *albumin* (or albumen) and *globulin*. The former is the same protein as we meet with in egg-white.

So, on analysis, the blood plasma is seen to have the same constituents as the protoplasm of the amœba (fully described in Chapter I, page 13). Are we then entitled to look upon the blood as a fluid mass of living protoplasm, or is it simply a solution containing the constituents we have described? To this problem, science has as yet found no answer.

The red blood corpuscles of the human body are like little discs hollowed out on each side (Fig. 2). They measure about one three-thousandth of an inch across and are about one ten-thousandth of an inch thick. When examined carefully under the microscope, they are apparently quite structureless. They have no nucleus—the hæmoglobin which gives them their red colour lies collected mostly round the rim of the corpuscle. As we explained in the previous chapter, they can squeeze themselves round narrow corners in the capillaries, so we may conclude that they are soft and elastic. In lower animals and in all embryos, the circulating blood cells are true cells and have nuclei. In mammals, including humans, the red corpuscle cannot be truly alive because it lacks a nucleus—and, in fact, exists only a relatively short time before it is destroyed.

Fig. 2. Typical red corpuscles enlarged 150 times.

The great advantage of having so many of these small discs of hæmoglobin in the blood is that an enormous surface is prepared on to which oxygen can be taken.

If you take an apple and cut it up into small parts, although you do not alter the volume of that apple, the smaller the pieces you cut it into, the more you increase the surface exposed to the air. So that in the case of objects the size of red blood corpuscles, the area exposed is enormous in relation to the volume of red corpuscles present. This surface area has been calculated to be about one thousand five hundred times as much as the surface of the whole body. All this is available for catching oxygen and giving it to the tissues.

HOW HÆMOGLOBIN WORKS

The hæmoglobin which we have mentioned so often as the most important element in the red blood corpuscle is a very complicated substance. By breaking up red blood corpuscles they can be liberated to form small crystals. These, when examined, are found to consist of a kind of complex protein. This protein can in turn be broken up into a substance called *globin* and a pigment known as *hæmatin* (pron. : heema-tin), which contains iron. If hæmoglobin is exposed to oxygen it quickly unites with it, but this compound is very unstable and the oxygen is readily given up (as happens in the tissues). When this happens, the colour of the pigment changes

from bright red to dark bluish-red. Blood in the arteries is the bright red variety, for it contains oxygen; blood in the veins is the bluish-red variety, for it has lost its oxygen.

Other gases besides oxygen can combine with hæmoglobin, in particular carbon monoxide. This gas, as well as carbon dioxide, is formed when fuel burns. It is therefore present in the flame of an ordinary coal fire, producing the flickering blue tongues of flame that are so beautiful in colour. It is particularly liable to be formed where burning goes on with an insufficient supply of oxygen. This condition is often present when a car is started up on a cold morning inside a garage with the doors closed, and it is carbon monoxide gas which has been responsible for death under these circumstances.

WHY CARBON MONOXIDE POISONS US

Carbon monoxide has a very strong affinity for hæmoglobin—much greater than oxygen—so that even if present in a very low percentage in the atmosphere, it turns out the oxygen from the hæmoglobin molecule and forms *carboxy-hæmoglobin*. This substance is a bright cherry-red colour, and if taken up by the lungs into the blood it is carried to all parts of the body. When this happens, the brain cells cannot get any oxygen from the blood, and drowsiness, leading to unconsciousness, is the first sign of poisoning from this odourless gas. The result is that the victim makes no effort to get out of the garage, for the apparatus for thought and judgment which would tell him he was in danger is just the first part to be affected. So the tissues and vital parts of the brain are deprived of their oxygen and suffocated to death. If the body organs are examined after such a death they are found a bright pink from the new pigment in their blood.

A very similar thing happens with prussic acid or cyanide poisoning. Very quickly, in a few seconds, the hæmoglobin is changed, the tissues, especially the brain, suffer acutely, and death occurs suddenly, often within a few seconds.

THE BODY'S NEED OF IRON

We mentioned before that hæmoglobin could be split up into hæmatin and globin. The hæmatin contains a small but an essential amount of iron, which is obtained from iron traces in the food—particularly in fresh fruit and vegetables. If there is insufficient iron in the diet, then hæmoglobin cannot be built up and the red blood corpuscle has too little hæmoglobin in it. Then the blood becomes pale and the body as a whole, anæmic. On the other hand, anæmia may be due to the fact that there are too few red corpuscles in the blood though each is carrying its full quota of hæmoglobin. This can be ascertained by doing a blood count.

Let us now follow the life history of a red blood corpuscle.

The first red blood corpuscles to be formed in the little embryo (that is, the developing child in its mother's womb) come from the yolk-sac (for human eggs have their yolk as well as hens' eggs). In this part of the embryo, primitive cells first group themselves into columns which become hollow in the centre. These are the first blood vessels. The cells in the centre of the column form blood cells, while those on the outside become the wall of a blood vessel.

At the same time the system of vessels in connection with the heart of the embryo is also developing. This system, lined with smooth endothelium, contains only fluid plasma and is at first separate from the vessels of the yolk-sac. By the time the embryo is three weeks old these two sets of vessels have joined up. Now the primitive blood cells, which are nucleated, flow into the embryo's blood vessels. By adult life, as we have seen, the nuclei have disappeared in mature red corpuscles. For some while, liver and spleen take on the function of building new blood cells, but finally, this is taken over entirely by the marrow of bones. At first, all the bones are busy forming cells; later, as fewer cells are required, this area of formation shrinks from the extremities towards the centre, that is to say the bones of the feet, legs and lower thigh, give up forming the cells, and the marrow of these bones turn from red to yellow (Fig. 3). In the adult, therefore, blood is being formed only in ribs, spine, shoulder-bones, pelvis, and the upper ends of the arm and thigh. Here, blood is formed without ceasing all through life.

The ripening of a mature red blood corpuscle from these cells in the bone marrow is a complex process. But if one imagines a closed space, lined with primitive cells, called a *sinusoid*, one has pictured

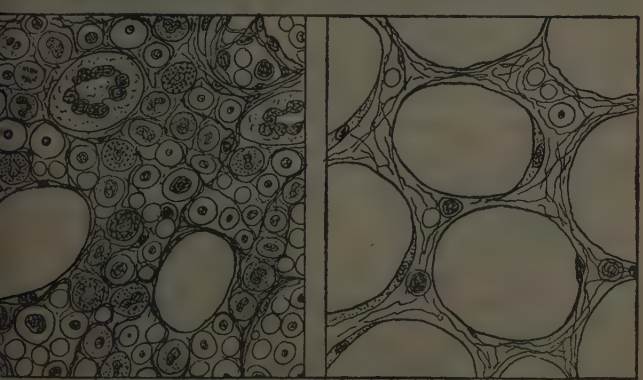


Fig. 3. *Differences in bone marrow;* (left) *while actively making blood cells;* (right) *having given up this work.*

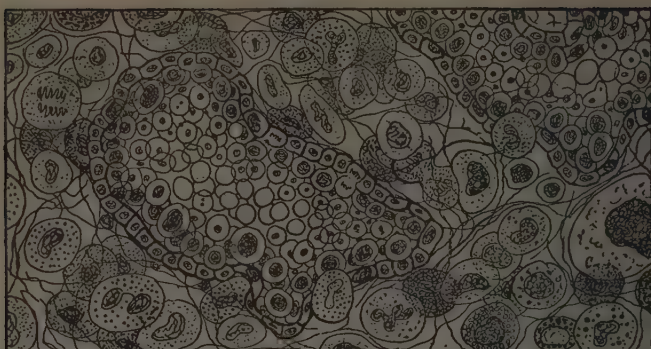


Fig. 4. Red marrow enlarged 500 times showing red blood cells being built up inside the sinusoids, whilst early white blood cells lie outside

the unit of this cell factory. In Fig. 4 you see such a space, round which are layers of cells. These are ripening stages of red blood cells whose names we shall omit. The most immature cell has a large nucleus and rather scanty cytoplasm which contains no hæmoglobin at all. Gradually the cell becomes smaller and the nucleus fades away, or is cast out of the cell. At the same time as this is happening, hæmoglobin is increasing. As the new red blood corpuscles are formed, they stick together in the shelter of the sinusoid, until finally they leak out at one end and are washed into the blood stream. In Fig. 4 you will see many larger cells in the area outside the sinusoid. In this area is the factory for the white blood cells to which we shall return later.

But just as an apple needs sunshine and air to ripen it, so the primitive forms of red cell inside the sinusoids need their own particular brand of sunshine. This consists of a substance called the hæmatinic factor, stored in the liver, as well as iron, vitamin C, and a chemical known as *thyroxin*. All these must be present in order that the growing red blood cell may thrive.

If the hæmatinic factor from the liver is absent, then the marrow struggles to prepare more blood, and in doing so spreads again down all the long bones, which it left in childhood—to the lower leg and feet, for example. But all to no avail, for only primitive forms of blood cells can be reproduced in these bones and they are deficient in hæmoglobin. So the blood becomes poor in mature red corpuscles, and abnormal cells with nuclei enter it to do their best to carry on. This disease is known as "pernicious anæmia," for until about ten years ago the sufferers invariably died. Modern research has shown, however, that what these patients lacked was

ne liver factor, so that liver given either by mouth or injection is ow saving thousands of lives which ten years ago would have had o be forfeited.

COMPLEXITIES OF THE BLOOD

But let us follow our red blood corpuscle on its journeys. It will xist perhaps for three weeks. It is not alive now; it is just a little ag of hæmoglobin, passively taking up oxygen in the lungs and iving it up in the tissues. Sooner or later its doom will overtake . Destruction of red blood corpuscles takes place mostly in the pleen, but also in other organs such as the bone marrow, liver, and ven lungs—wherever, in fact, there exist cells of a very special rpe which have been rather lengthily named the *reticulo-endothelial* ystem. (We shall refer to them as R.E. cells for brevity.) The ame simply describes the fact that they are derived from a special ell, found in spleen and bone marrow—the reticulum cell—and are elated also to endothelial cells, which, as we have seen, form the ning of blood vessels.

In liver or spleen, therefore, we may come across large white cells ontaining the remains of devoured red blood corpuscles—a picture rangely reminiscent of an amœba devouring its food.

But in destroying the red corpuscles, the body does not waste such vital element as the iron which they contain. So the hæmoglobin as its iron split off and stored away; the residue is changed to a igment known as *bilirubin* (pron.: bill-y-roo′-bin). This is carried long the veins from the spleen to the liver where it is excreted as ile. Meanwhile, the iron is used again to build up fresh hæmo- lobin in the ripening red blood corpuscles of the bone marrow. The bilirubin which is formed in spleen and bone marrow is a olden-coloured pigment, and if an excess of red blood corpuscles destroyed, the golden colour can be seen in the whites of the eyes, r on the skin. This is one form of jaundice.

VARIOUS TYPES OF WHITE BLOOD CELLS

In the microscopic section of bone marrow, seen in Fig. 4, there re collections of cells outside the sinusoids that contain the maturing ed cells. These, as we mentioned, are developing white blood cells. There are various kinds of white cells in the blood, totalling about ight thousand per cubic millimetre in all—or something less than fty millions in the whole body. These various types can be picked ut most clearly by special methods of staining with dyes, but rawings of some of them are shown in Fig. 5. It will be noticed iat some have granules, some not. The granular cells are of three rpes. Some granules stain red with a dye called *eosin*, and these re therefore called *eosinophile* cells. Some stain blue with certain asic dyes, and are called *basophile*, while others, and by far the

commonest, stain an intermediate colour—these are *neutrophile*

These faintly granular cells sometimes show peculiarly sh nuclei, in so far as they are often divided into " lobes " as ca seen in Fig. 5, and these many-shaped, neutral-staining white which form seventy per cent of the total of white cells, have as main function the defence of the body against infection. Wat under the microscope when alive, they can be seen to put protoplasmic limbs and move from place to place, just like am

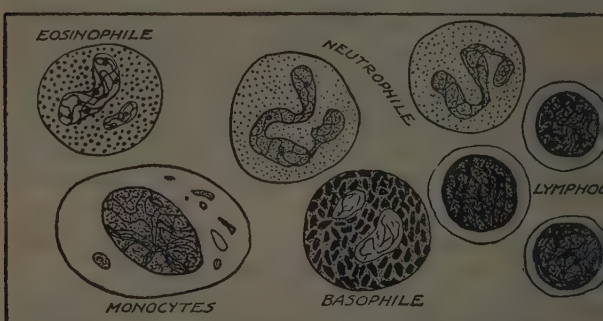


Fig. 5. Types of white blood cells enlarged 1,000 *times.*

When the body is invaded by certain types of bacteria, particu those types known as staphylococci and streptococci, the white engulf the invading germs, as seen in Fig. 1 on page 12. activity is called *phagocytosis* (" cell-eating," pron.: faggo-sy-to'- they dissolve and digest their defeated foes. This they can d virtue of the fact that they are particularly adapted to digest pr breaking it down into simpler substances, and so killing any thing such as a coccus that they absorb. If the white cell dies, then the enzyme or ferment (by means of which it d protein), which has been held in check by the living cell, now upon its dead body, digesting both bacteria within and cell. The result is a yellow liquid which we call " pus."

Any invasion of the body by the common bacteria results urgent message to the bone marrow for more white cells, wit result that these rush out into the blood stream, collect aroun infected part, and form a ring round the invading bacteria. they hurl themselves on to the bacteria, being drawn to their by the poisons that the bacteria contain. Thousands of cell bacteria die in the struggle, forming an abscess cavity full o which is the battlefield. Finally, the abscess usually bursts white cells with dead and living bacteria drain away from th

conflict—the battle is won, and healing can now go on.
eosinophile cells have large bean-shaped nuclei, and have
cytoplasm crowded with large coarse red granules. These
orm only about three per cent of the white cells of the blood.
do not eat up bacteria like the common white cells, but
appear in large numbers, sometimes in conditions where
sues are over-sensitive to a protein irritant, but particularly
eases of the skin. In Chapter IV, page 109, we mentioned
rash following the eating of shell-fish. This condition,
a, and invasion of the gut by worms, are all states in which
sinophile cells are likely to accumulate. What they actually
ot known.

basophile cells, the last of the group of white cells, have
lobed nuclei, with heavy blue granules in the cytoplasm.
cells are very rare; less than one in a hundred is found.
ow only that they play no prominent part in common diseases.

THE WORK OF LYMPHOCYTES

next most numerous group of white blood cells is the
ytes. These are small round cells, almost all nuclei when
icroscopically. Though so numerous, it is still very difficult
exactly what part they play in disease. They increase in
r in many chronic infections which go on over a long period,
s tuberculosis. They group round cancer cells when these
deeper tissues, and there is little doubt that they arrest the
ss of the growth considerably, but how they do it we do
ow. Seen living under the microscope, they move slowly
ugs, compared with the active neutrophile cells.

IMPORTANCE OF MONOCYTES

third and last group of white blood cells is the *monocytes*.
cells are large with a round nucleus, and plenty of cytoplasm.
are not very plentiful in the blood, forming only about five
nt of the total white cells, but they are very important, for
ossess the power of engulfing any foreign particles they come
to an exceptional degree, being even more active than the
ner white cells at this task. It is cells of this type that
the worn out red blood corpuscle, in the way described
usly, and it is largely these cells which constitute the R.E.

R.E. system has been understood only of recent years. It con-
cells of various types scattered over different parts of the body,
in the liver and spleen. These cells, like the neutrophile
cells, have the power of eating bacteria, that is phagocytosis.
that happen to be in the blood are called the monocytes.
however, develop in the tissues outside the blood, where

they retain their phagocytic properties. Here they may be fixe in one spot and are called fixed tissue cells, or wander through th tissues (wandering tissue cells). Some are found lining the bloo vessels of liver and spleen, like endothelial cells, differing fro them only in that ordinary endothelial cells lining blood vesse cannot engulf foreign particles as these can. If Indian ink, fo example, is injected into the blood, small granules of the pigme are soon found collected in these cells in the liver and spleen a well as the bone marrow. They will also be found in the monocyt of the blood. It is thought that what happens to Indian in particles probably happens to bacteria or their toxins. In an case, there is evidence that this R.E. system has a direct relatio to resistance against disease, and the establishment of immunity.

WHAT DO WHITE CELLS DO ?

One must remember, however, that phagocytosis is not only reaction to bacteria. The osteoclasts which we saw in Chapter I eating away bone, are doing the same thing under special circun stances. The tadpole's tail disappears under the influence exactly the same process. It is not so easy to follow the life histo of white blood cells as red, and dispute on some of the main par of the story makes it no easier. But we do know that primitive whi cells exist outside the cell-forming areas of the bone marrow, th these are formed probably from the cells of bone marrow, and all come from a common root stock.

These primitive cells ripen just as did the early red cell form until the mature cell works its way out into the blood strea This accounts for the appearance of the *granulocytes*.

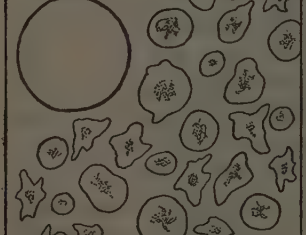


Fig. 6. A red b'ood cell and some platelets enlarged 1,500 *times. Note the difference in size.*

Lymphocytes are formed in t lymph glands, which, as we me tioned in the previous chapter, a scattered all over the body. first they appear in the centre the body, but later are work into the lymphatic canals when they enter the blood stream the thoracic duct. Some, no doub are formed in the bone marro as well. The monocytes we ha seen, originated from the R. system of lymph glands, splee and other organs.

Besides the red and white cc of the blood, there is a third kin of formed element—the *platel* (Fig. 6)—numbering about thr

hundred thousand per cubic millimetre. These small bodies are about a quarter the size of red blood corpuscles. When stained, they disclose a darker coloured central part, which, it has been suggested, represents a nucleus. But this is undecided. In the bone marrow are found some very large cells which thrust out long limbs in all directions like a large amœba. Many of these limbs—or *pseudopodia*, as they are called—break off and are washed into the blood stream; these are the blood-platelets.

THE VALUE OF THE BLOOD-PLATELETS

These small bodies are of enormous value to the body in that they control the process of the clotting of blood. This miracle happens so often to us that we tend to forget it, and only express annoyance that a cut received whilst shaving goes on bleeding for so long. But why should it stop? Why should it not go on for as long as there is blood to lose?

John Hilton, a famous surgeon to Guy's hospital during the nineteenth century, writes in his book, *Rest and Pain*, this vivid passage: "Let us imagine our first parents suddenly thrust out of the garden of Eden, and doomed to toil for their daily bread; with hands unused to labour . . . and exposed to all the accidents of a precarious existence. Let us try to realize the awe-stricken dismay which must have oppressed man's mind on the infliction of his first wound, his first experience of pain; the breach of surface disclosing to his sight his blood, flowing unceasingly, or leaping at sustained intervals from its opened chambers, his sense of fainting, and his ultimately sinking on the earth under the foretaste of death. Can words depict the hopeless anguish he must have endured? But what follows? See him awakening to life again, the stream of blood stayed, the chasm plugged, his strength revived and, day by day, that wound—which he regarded as the badge of death, the vengeance of the Creator's wrath—narrowing and healing till it could hardly be seen." Such is a Victorian appreciation of the clotting of the blood.

This clotting is by no means a simple process, and unfortunately it is shrouded in a mist of names and theories. We shall mention here only what is generally accepted to be true.

HOW BLOOD CLOTS

We saw above that blood contained a substance fibrinogen, and that when blood was shed this turns into threads of fibrin. The next obvious question is what turns the fibrinogen to fibrin? This is a substance called *thrombin*. Now if thrombin was normally present in the blood, clotting would be going on any time in various parts of the body. This would not do at all—and, in fact, thrombin is absent from the circulating blood. In its stead there is another

substance, *prothrombin*, and with it we have at last reached th beginning of this complex chain of events.

If prothrombin is acted on by calcium (which is also normall present in blood) and another substance, *thrombokinase* (pron. throm-bo-ki'ne-ase), then it will form thrombin. Here it is that th blood-platelets come in, for when they are destroyed they liberat thrombokinase and so start off the clotting chain.

FUNCTION OF THE PLATELETS

Now platelets have as their great function the repair of any injur to the blood vessels. As long as that smooth lining of cells (th endothelium) is intact, the platelets take no notice. But if for an reason this endothelium is broken, then platelets flock to the spo plaster themselves over the injured part and in doing so break up thus liberating thrombokinase and beginning the clotting proces The same happens when blood is poured into a jar. The platelet in foreign surroundings with no endothelial-lined spaces aroun them, break up and start the clotting process.

Sometimes blood vessels of the body, particularly veins, afte operations, or as a result of being " varicose " in the leg, becom diseased. Platelets immediately form on the diseased area Clotting occurs, so that fibrin is laid down over the spot. If th area is large, then the whole vein will become filled with a clot this is called *thrombosis*, the clot being known as a *thrombus*. Thi thrombus covers the injured area which, in the course of time, i repaired, the thrombus itself contracting and often being covere by endothelial cells, so that later the vein again is an open channe

IF THE PLATELETS ARE DESTROYED

But blood-platelets may vary. Born of the large cells in the bon marrow, the platelet after a short life is destroyed, like the re blood cells, probably by the spleen. But if the platelets are to fragile and break up too easily, or the spleen is too voracious, the their numbers in the blood drop, until from a normal three hundre thousand per cubic millimetre they may reach only fifty thousan Then bleeding will occur spontaneously and spots may appear o the skin, nose bleeding and blood in the urine may appear, and th patient become seriously anæmic as a result of lost blood. Thi condition is known as *purpura*. On the other hand, bleeding of thi nature sometimes occurs, although we can find no deficiency of th platelets. This is one of the many mysteries of the human body.

But the opposite may happen—blood may be shed, or bloo vessels be injured, yet the platelets, though present in adequat number, refuse to break down and start the clotting. The resu is that the hole in the blood vessel remains open and the bleedin goes on. This is what happens in *hæmophilia*, the bleeding diseas

which we mentioned in Chapter II, page 52, when we noted its peculiar inheritance.

Clotting of blood, then, is one of the methods by which the body protects itself against the accident of mechanical injury such as cuts and lacerations. But there is another form of accident in which the blood plays a large defensive part—infection.

When bacteria invade the body they attack in two ways : the first is by multiplying, so that given a chance they soon reach enormous numbers, and the second is by secreting poisons or *toxins*.

Accordingly, the body has developed two main lines of resistance in the form of *antibodies*—one against bacteria and one against their toxins.

Imagine that the bacteria have won the first round, and have established themselves on the skin or invaded the mucous membrane. They now secrete toxins which soon enter the many blood vessels that open up in the vicinity. As these toxins circulate, they come into contact with cells of the spleen, lymph glands and bone marrow. These at once manufacture a substance to neutralize this toxin, called *antitoxin*. If produced in sufficient amount all the toxin is neutralized, and all the symptoms, such as headache and exhaustion, which it was producing, disappear. But note that the bacteria themselves are not touched by antitoxin, and may still thrive. The antitoxin produced is quite peculiar to the kind of bacteria concerned; for example, the antitoxin that neutralizes scarlet fever will not neutralize diphtheria.

HOW PEOPLE CAN "CARRY" DISEASES

The interesting point is raised also, that if a person can produce enough antitoxin when invaded, he may harbour the bacteria but have no symptoms of the disease. This happens in actual fact. Such people are known as "carriers," for they may communicate the bacteria—and so the disease—to people less fortunate with their antitoxin supply. Often, this type of thing happens in people who have had a disease which gives immunity, such as typhoid. Although the patient recovers and feels well, he may remain infectious to others. Special precautions and tests are always made, therefore, to prevent this happening.

"Typhoid Mary" was a notorious woman in America, who happened to be a cook serving hundreds of meals and a carrier of typhoid as well. The result can be guessed. A "carrier" working in a London well has also recently caused an epidemic.

In diphtheria, prepared antitoxin is most valuable, for given early, it markedly diminishes the severity of the symptoms and complications, and so the danger to life. It must be given in the first day if possible, before the bacteria have got the upper hand.

Besides the antitoxins, the body produces an antibody which acts

on invading bacteria themselves. This again is carried by the blood. The extermination of bacteria is not so simple as the neutralization of their toxins, though equally, or even more effective. If bacteria enter the blood, they evoke from the R.E. system an antibody called *amboceptor* which is quite specific, as was the antitoxin. But this amboceptor can do nothing on its own. It links up with the bacterium, but cannot destroy it unless with its other hand it grasps another substance always present in blood, called *complement*. This complement, then, is the axe of the executioner (amboceptor) and in a stroke the criminal bacterium is dissolved and disappears.

This property of disposing of intruders into the blood stream is not confined to bacteria. The same happens if foreign red blood cells are injected; amboceptor is made and complement destroys them, liberating the hæmoglobin from the destroyed corpuscle. This is known as *hæmolysis* (pron.: heem-o'l-y-sis).

INFECTION AND IMMUNITY

Other forms of antibodies are produced in the blood after infection. We have already noted the agglutinins with respect to the risks of blood transfusion. The principle is exactly the same with regard to invasion of the blood, not by foreign red blood corpuscles, but by foreign bacteria. The bacterium taking the place of the foreign red blood corpuscle acts as agglutinogen, producing the antibody —the agglutinin.

This causes the bacteria to clump together, just as the red corpuscles did. This agglutination is of much more importance in diagnosis than in treatment of disease. In typhoid fever, for example, these agglutinins act on the bacilli in this way, so that a test can be done in a doubtful case, by taking the patient's serum and testing it against known typhoid bacilli. If they are strongly agglutinated, then we know that he is suffering from typhoid.

HOW THE BLOOD FIGHTS INFECTION

Precipitins are another form of antibodies which appear in the blood during illness. We mentioned them before, in describing how the closer two bloods were related, the less was the precipitin formed—so that man's and the anthropoid ape's blood did not produce precipitins when mixed, whereas rabbits' and man's did. The more foreign the protein injected into the blood, the more likely as a general rule is it to produce disease. A precipitin is a response to this foreign protein, whether it be incorporated in the body of a bacterium or not.

Now, although there are all these efficient methods of combating infection in the blood, one must not forget the important part taken by the cells. Phagocytes of all kinds, as we have seen, engulf

acteria and dissolve them in their cytoplasm. A curious mechanism exists whereby the body provides these phagocytes with a substance called an *opsonin*. This is a kind of sauce to the devouring cell, or if plasma is deprived of opsonin, as it quite easily can be, bacteria and phagocytes mix without touching each other. As soon as a little serum is added with opsonin in it the phagocytes make a feast (which is what the word opsonin means).

All these methods then, are in the blood at the body's disposal to fight disease. Can we not make use of them in some way for prevention of disease—so much better a thing than curing it?

DISEASE AND IMMUNITY

Our problem is that of immunity. How can the body be made immune to disease?

There are various types of immunity, and we must first separate these out. For example, there is a natural immunity by reason of which different animals suffer from different diseases. Invertebrate animals are not attacked by the same bacteria as vertebrates. Dogs do not get typhoid fever. In these cases bacteria may be present, but they live quietly in the tissues without harming them in any way. Why the typhoid bacillus should invade the human intestine so dangerously and leave the dog's alone, we do not know.

Similar to this there is racial, and species, immunity—not very marked in the races of men. And, finally, of this type there is individual immunity, known to all of us. Of the people who drink infected water containing typhoid bacilli, some only develop the disease.

But immunity, if not born with the body, may be made in the course of living by the creation of the antibodies we have just described.

WHAT IS ACTIVE IMMUNITY?

Active immunity is a term used to describe the fact that the body itself—in large part the R.E. system—has manufactured these antibodies. This is often obtained by having recovered from an attack of the disease in question. For example, a person who has had smallpox will not have it again. This fact was known in the eighteenth century. But smallpox seemed to have malicious preference for young children, and death more often ended the scene than immunity. How could one modify the disease so that immunity resulted with a minimum risk of death? The first person to tackle this problem was Lady Mary Wortley Montagu, who observed the practice in the East, of inoculating people deliberately with matter from smallpox vesicles—and that the resulting disease was habitually milder than if it was caught in the usual fashion.

But in England, though this was found to be largely true

it was not mild enough, and many still died from the disease even although it was contracted in this deliberate way.

The genius of Jenner came to the rescue. He noticed that the milkmaids in Gloucestershire often got *cowpox* on their hands after milking. He also noticed that these very milkmaids always escaped the many smallpox epidemics that ravaged the countryside. So he suggested that cowpox should be inoculated as a preventive of smallpox. This he did to a farmer's son, and later, to prove his point, inoculated him with the true smallpox. It was an anxious time for Jenner—and for the world—had it but realized. The weeks passed away and the young lad, no worse for the experiment, was the first to benefit from the greatest preventive discovery—vaccination.

INOCULATION AND IMMUNITY

What had happened? The cowpox virus is smallpox, modified by passing through the body of a cow. If then injected into man it gives cowpox—a very trivial disease in which there is a little temperature and soreness, but in which the blood becomes full of antibodies to the virus of smallpox, so that if this now invades the body the antibodies kill it off before it can produce any disease.

In this way we can create immunity in the body by inoculating it with modified organisms of disease, so that antibodies are produced without the risk of the true disease.

In practice, a *vaccine* (pron.: va'k-seen) consists of various modifications of disease-producing bacteria. Some have been killed, others grown in such a way that they are very weak. Vaccination against cholera, typhoid and plague is carried out, using dead bacteria. In all these, the body produces its own antibodies.

PASSIVE IMMUNITY

Passive immunity occurs where the antibodies are made by another body, man or animal, and introduced into the blood. For example, a horse is injected with small but increasing doses of diphtheria toxin (the poison from diphtheria bacilli). As time goes on, the horse produces antibodies in increasing number until large doses of the toxin cause no effect. The horse has become immune, with plenty of diphtheria antitoxin in its blood. If the horse is now bled, and the blood serum separated out, this will contain enormous quantities of diphtheria antitoxin, which can be injected into children with the disease, supplying them with just what they are struggling to produce themselves.

It does not require much imagination to see how many lives can be saved by early and adequate doses of diphtheria antitoxin.

Diphtheria antitoxin may also be given to those who have been in contact with a case of diphtheria so that the blood is prepared

st any onslaught of the diphtheria bacteria that may come to it. Even the poisonous toxin has been modified in various ways, so hat the human body plays the part that the horse's did in the manufacture of antibodies. By this means immunity may be obtained from diphtheria lasting for years, whereas the passive mmunity following antitoxin lasts only a week or two.

There is no doubt that if all the means at our disposal were dequately organized, diphtheria should become a disease of the ast, in much the same way as smallpox.

Unfortunately, with many other diseases the story has not been fully mapped out as with diphtheria. Either the bacterium does ot excrete its toxin, but locks it in its body, so making it difficult collect, or results of injections have not been so successful as nticipated. But these difficulties will, undoubtedly, be conquered time as the war against disease progresses.

We have reviewed the blood, then, from many sides and seen that plays a part in feeding, cleaning, warming and defending the ody. It is a simple tissue with many parts to play. In all these carries messages from one organ to another, it transforms the gans from a chaos of unregulated action into an harmonious hit, the body. In short, it integrates.

CHAPTER VII

THE BREATH OF LIFE

You take about twenty-five thousand breaths a day, and you are probably not aware of one. Surely, the astonishing mechanism which works this miracle is one well worth quiring into.

But before we describe the act of breathing let us get our ideas ear as to exactly what is its essence and its object.

In Chapter I, we noted that respiration was one of the charac-ristics which distinguished the living from the dead. All living ings, from the amœba to man, breathe, and by this act they take oxygen from their surroundings. Inside the cell this oxygen mbines with the carbon present in all living things to form the s called *carbon dioxide* (CO_2). It also may combine with hydrogen form water (H_2O). Now all cells must work for their living, ther chemically or mechanically. For example, a muscle cell ntracts, and a gland cell secretes. In doing so, they both burn up el consisting of complex materials with carbon and hydrogen in rm.

This " burning " consists, as we saw, in combining with oxygen form, from the carbon part, carbon dioxide, from the hydrogen

fraction, water. The heat of the body is also produced in this way. Just as the energy from burning coal may be turned into all the power of a steam engine, and into heat as well, so may the fuel of the body. Now respiration, or breathing, in its widest sense includes all this process of oxygen retention in the cell and carbon dioxide expulsion. It is, perhaps, the most vital link of life's chain, even more vital than food. For a man may survive food starvation for weeks, as in a " hunger-strike," but starve him of oxygen and he dies in a few minutes.

As life evolved from its simple earlier forms, various methods for maintaining the oxygen supply of the body developed. Insects, for example, evolved a complicated system of " air-tubes " which form a network through the body, so bringing the oxygen into extensive contact with blood in a way suitable for the exchange of gases. Fishes solved the problem by means of gills, whereby the blood which has already been used (venous blood) is pumped into a number of vessels with a large area, over which flows fresh water that contains plenty of oxygen. In consequence, the exchange of gases, oxygen and carbon dioxide, is made easy. Frogs do a certain amount of their breathing through their thin skins. Mammals, with man at their head, adopted the expedient of a lung.

THE NATURE OF BREATHING

Respiration may be looked upon in two ways. First it consists of the act we know of as breathing, whereby air is drawn into the body in such a way that oxygen is retained and carbon dioxide is expelled—this is respiration from the point of view of the body as a whole. Secondly, one must consider the cell. Respiration of the tissues is a linked but different process. It presents its own problems. But in both the chemical principles are the same.

Let us first, therefore, describe cell-respiration. The exact way in which oxygen combines with the carbon and hydrogen of the cells is not yet known. For one thing, the tissues burn at such a low temperature—that of the body 98·4 degrees Fahrenheit. Compare this with the temperature of a flame of fire. There must be in the cell, therefore, substances which hasten on the process enormously. They are known as enzymes, which have been described earlier. These hasten on the speed of a chemical reaction which otherwise might progress so slowly that to all intents and purposes it could not be said to exist. In the cell the enzyme that quickens up the process of absorbing oxygen is called an *oxidase*. Without it the cell would most certainly die, for it is to the cell what the lungs are to the body as a whole.

Now oxygen and carbon dioxide are gases, and it may seem difficult to grasp how the gas in the air we breathe can be turned into the liquid state, in which it is utilized in the fluid surrounding

he cells. The whole process of solution of gases in the blood is very important, and a knowledge of the simple laws of physics helps enormously in the understanding of the process of respiration. For it is a remarkable fact that from the lungs to the tissues, the behaviour of the blood gases, oxygen and carbon dioxide, is controlled by physical laws, just as much as in a laboratory experiment. There is no "vital" action present which alters these laws.

WHAT IS A GAS?

A gas is a substance in which there are many small particles. These are scattered at a distance from one another. If they are pressed together sufficiently, the gas will become a liquid—like liquid air. In a liquid, therefore, the particles are closer together, and in a solid closer still. Since the gaseous particles, or molecules, are scattered, they can penetrate through the atmosphere rapidly. One knows this by the spread of some evil-smelling gas in the still air of a room. This spreading process is called *diffusion*. Now if a gas is put into a jar, all its particles will be bombarding the sides of that jar to get out and diffuse. The more pressure that is put on the gas—that is, the more it is compressed—the closer will the particles be together, and the harder they will bombard the jar walls, until they may break it. When this happens, we say the jar has "exploded."

But besides the force of the gaseous particles, there is another, gravity, to be taken into account. Gases have weight, like everything else—that is to say, gravity attracts them to the earth. In the case of the gases of the air, gravity attracts them with a force that is found to be capable of balancing a column of mercury seven hundred and sixty millimetres, or about thirty inches, high. This force is known as barometric pressure, and it represents a fact that is most essential to the act of breathing as we shall see later.

IMPORTANCE OF THE SOLUBILITY OF GASES

Gases can dissolve in water, and any one who has taken the stopper off a ginger-beer bottle knows that if the pressure is lowered (as by unstopping the bottle) then gas rapidly comes out of solution (fizzes) until a new equilibrium is established.

This solubility of gases must be standardized in science, so that the solubility of different gases may be compared. The number of cubic centimetres (c.cs.) of gas dissolved in one cubic centimetre of fluid is called the *coefficient of solubility*.

Whereas one cubic centimetre of carbon dioxide will dissolve in one cubic centimetre of water, under standard temperature and pressure, only 0·03 cubic centimetre of oxygen will do so.

The amount of a gas going into solution depends on temperature, pressure and solubility. The higher the temperature, the less gas

goes into solution. The greater the pressure, the more dissolves. If two gases are present together in a fluid, then the amount dissolved depend on the pressure of each on the fluid surface. This applies to the atmosphere which consists of oxygen (twenty-one per cent) and nitrogen. The pressure of oxygen is twenty-one per cent of seven hundred and sixty millimetres, or about one hundred and sixty millimetres of mercury. On this pressure depends the amount of oxygen dissolved. When sufficient oxygen has been absorbed then the gas stops flowing, either from fluid to air (as when the ginger-beer bottle was opened) or from air to fluid.

Now if the blood in the lungs consisted of a watery solution with no hæmoglobin in it, then by these laws of gases in solution only a very small fraction of oxygen would be dissolved into the blood—about one-fortieth of what is actually found to be present. With this supply the tissues could not live.

This is where hæmoglobin enters the story. We have already seen how this extraordinary pigment carries the greater part of the oxygen of the blood to the tissues. But what carries the carbon dioxide which the cells give off? This is carried by the alkalis of the blood, such as sodium bicarbonate, not so much by the hæmoglobin.

WHAT RESPIRATORY EXCHANGE MEANS

We are now in a position to follow the process of *respiratory exchange*, as it is called. For the mechanism depends essentially on the solubility of gases in fluids under varying pressures. In the lungs oxygen is present, exerting a pressure equivalent to a column of mercury about one hundred millimetres high. Venous blood which comes to the lungs, however, has been deprived of a lot of its oxygen by the tissues, and the oxygen tension is only about forty millimetres, so that there will be a flow of oxygen from lung to blood plasma. From here it is picked up by the hæmoglobin until this can hold no more; it is then in a state which is called "saturated." Note that the oxygen has had to pass through a thin membrane, the air-sac wall, to get into the plasma. This oxygenated blood now goes to the left ventricle of the heart which pumps it out to the tissues of the body. Here, opposite conditions prevail. Tissue cells are continually using oxygen, so the oxygen tension in the fluid around them is low, and oxygen must diffuse from the fresh plasma to keep up the supply. The hæmoglobin now discharges its loosely bound load of oxygen into the plasma because of its low oxygen tension or pressure. In consequence, from lung to tissue cell the pressure or tension of oxygen is steadily decreasing, this fact deciding the direction in which the oxygen flows, i.e., from lung sac to plasma, to hæmoglobin in red corpuscle, to plasma in tissue, to tissue cell, in that order.

With carbon dioxide the sequence of events is just the reverse. The active tissues produce it so that it is at high tension in them. Dissolving in the tissue fluids it forms carbonic acid, most of which is neutralized by alkali in the blood to form sodium bicarbonate. Arriving in the lungs the carbon dioxide in the lung air sacs is at a lower tension than that in the blood, so the carbon dioxide seeps through in the opposite direction to the oxygen (i.e., into the air sacs) whence it is breathed out into the air, so that expired air contains as much as four per cent carbon dioxide.

It was mentioned above that air consisted of twenty-one per cent oxygen, the remainder being nitrogen, water vapour and a very small percentage (0·05) of carbon dioxide. The nitrogen has no part in respiration. It is inert, and about one per cent is dissolved in both arterial and venous blood. As far as we know, it performs no function in the body, i.e., four-fifths of the air means nothing to us.

The respiratory tract has other things to do besides merely taking in the oxygen. Outside air is often not at all in a suitable condition

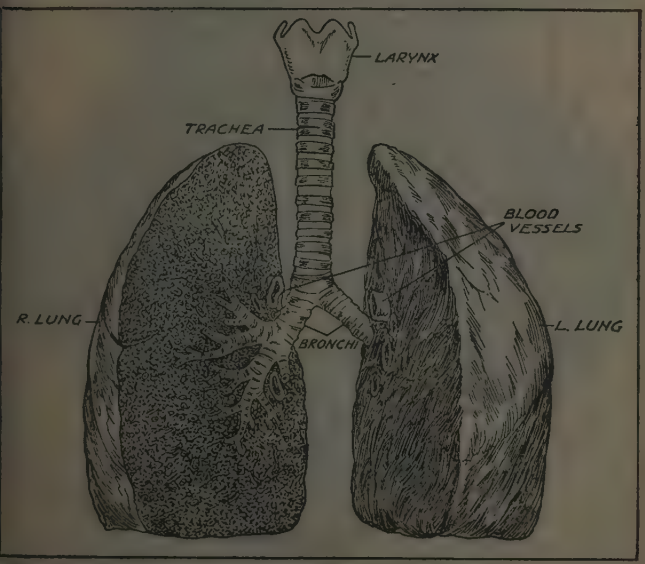


Fig. 1. The two lungs, showing how the main bronchi enter and branch in their substance. In the right lung the surface has been cut away to show how the air tubes branch.

to be drawn right inside the human body. For example, it may be very cold, and bodies are warm; it may be dusty, though dust may vary from none at all on top of a snow-capped mountain to enormous quantities in a London fog. Then there is moisture; the blood cannot afford to give out too much of its moisture to dry air—the body would dry up. All these additional problems must be solved, then, in the apparatus designed for breathing.

First let us follow a particle of air which commences its journey just outside the nostril. As a breath is taken in, this particle passes into the nose along a passage into the *pharynx*, or back of nose and throat. Here the air route overlaps the food route for a few inches. Soon they part again, the air travelling down past a flap, the

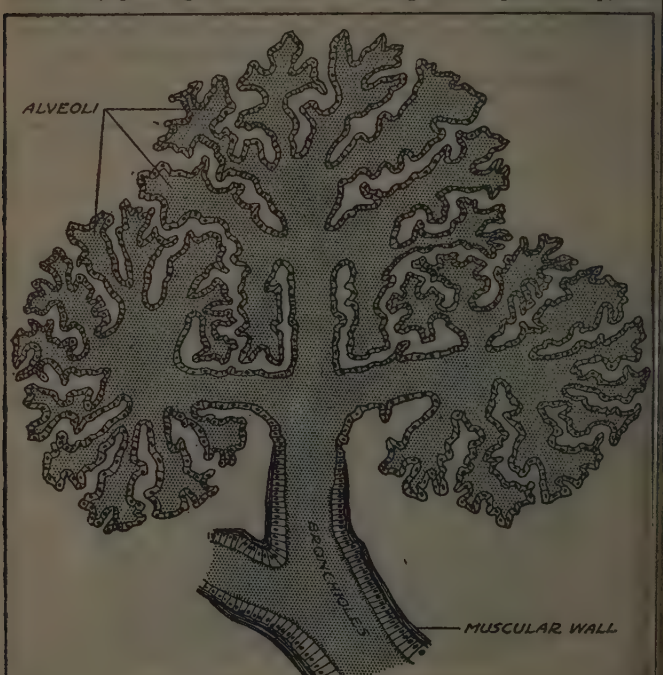


Fig. 2. Air sacs, or alveoli (enormously enlarged), of the lung. It is from these sacs that oxygen is absorbed into the body and carbon dioxide is breathed out.

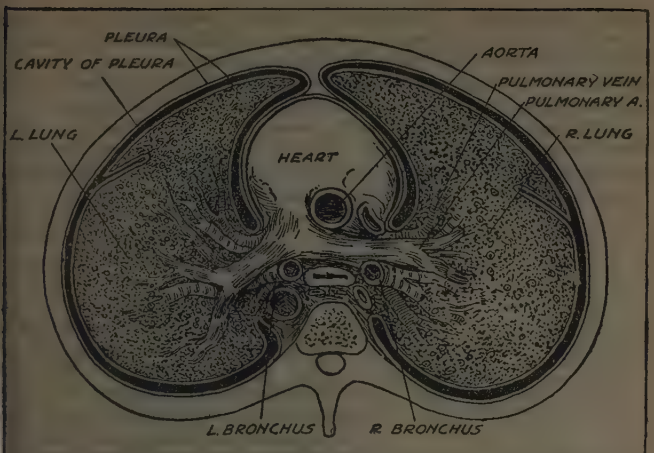


Fig. 3. *The chest cut across to show heart and lungs. Note the way the pleura lines the space between lungs and chest wall.*

piglottis (pron.: ep-py-glott-is), which forms the open lid to a round box-like opening, the *glottis*. Down it goes, now past the vocal cords in the *larynx*, or voice-box, into the trachea, or windpipe (Fig. 1). The windpipe consists of a series of rings of cartilage, one on top of another. These rings, which are elastic, make for mobility, while at the same time always keeping a way open for the air.

About half-way down the chest the trachea divides into two main bronchi. Of these, the left bronchus passes under the arch of the aorta to the left lung. The right carries on more in a straight line with the trachea. These bronchi divide, like the branches of a tree, into smaller and smaller twigs, which eventually lose all trace of cartilage in their walls and become narrow muscular tubes called *bronchioles* (Fig. 2). These in their turn branch into microscopic ducts which lead to the air sacs proper, or *alveoli* (pron.: al-vy-o'aly). Lining this tract are tall columnar cells with cilia, or waving tentacles, in the upper part. As the tubes get smaller, the lining cells become smaller, until in the alveoli themselves they are flat and very thin indeed, thus forming no obstruction to the exchange of gases. For outside the walls of the alveoli lie the capillaries of the lung arteries filled with blood.

Outside, the lungs are lined with a membrane known as the *pleura* (pron.: ploora). This ensheathes the whole lung (*see* **Fig. 3**), being attached at its constricted " root "; that is, where air tubes and

blood vessels enter it. From here the same membrane runs to the sides of the spine and round the inner wall of the chest, so that it forms a lining to the cavity in which the lungs move. From its inner surface the pleura secretes fluid which keeps the two surfaces lubricated, in a way very similar to the lubrication of a joint.

Air passes then, from the nose to minute air sacs in the lung. But what draws it? The lungs are filled with air by movements of the bony thorax and diaphragm (*see* Fig. 4). This fact and its mechanism was first worked out by one, John Mayow, in 1668, a physician and lawyer, who by the age of twenty-five had solved the problems of respiration, and at thirty-four was dead.

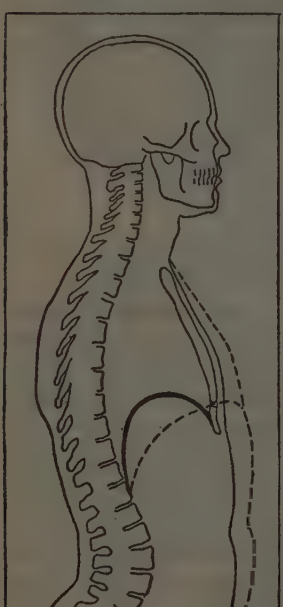


Fig. 4. Diagram showing how the breast-bone, diaphragm and abdominal wall move in the act of breathing.

"Breathing in," or *inspiration*, is brought about by enlarging the chest, the lungs expanding to fill the space. "Breathing out" is the opposite.

The process can be followed diagrammatically in Fig. 5. Here the bottle represents the chest wall, the tube passing through the cork is the windpipe, and the rubber balloon on the end the lungs. Imagine that the bottom of the bottle is made of an elastic rubber sheet, representing the diaphragm. When this sheet contracts it moves downward (this is what happens to the diaphragm in inspiration) so that the bottle cavity enlarges. This diminishes the pressure inside. But atmospheric pressure is pressing on the inside of the balloon, whilst a small vacuum is present on its outside, so that it will expand, until its elasticity, added to the pressure outside it, equals atmospheric pressure.

The mechanism for enlargement of the thoracic cavity is twofold, by rib movements, and by the diaphragm.

As we saw in Chapter III, the thorax consists of a closed cage, formed by the backbone behind and ribs sweeping round to the breast-bone in front. With inspiration the ribs are raised, thrusting the breast-bone forward and increasing the distance

between it and the backbone. This enlarges the chest from back to front. But also with each indrawing of breath each rib rotates sideways like a bucket-handle, so that the width of the chest is increased. These movements of the ribs depend on the intercostal muscles lying between them.

An up and down enlargement of the chest is obtained by movement of the diaphragm in a manner very similar to that of the rubber sheet in the bottle. The diaphragm is a sheet of muscle with a large central tendinous part. It forms a dome separating chest from abdomen, under which, on the right, is the liver, on the left the stomach and spleen. It is attached to the backbone behind, to the ribs all round at its edges, and to the sternum in front. Above, near the centre, the pericardium is fixed to it, so holding the heart in position.

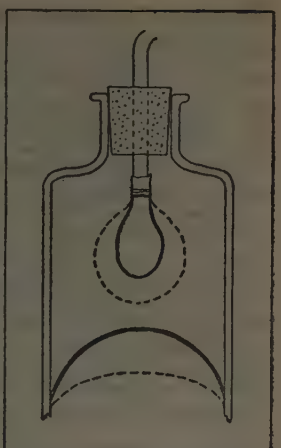


Fig. 5. Model of the act of breathing. (For explanation, see text.)

When a breath is taken the muscle fibres contract, drawing the central tendon downwards, the bases of the lungs follow and so expand in the space vacated by the diaphragm.

As it descends, this dome-shaped muscle pushes liver and spleen before it, so that the abdominal wall is thrust out.

To prove these points for yourself, take a deep breath and measure your chest expansion with a tape measure. Also watch the abdominal wall move forward with each indrawn breath, and fall back again on expiration.

Expiration in contrast to inspiration is almost entirely a passive recoil. The elastic lungs are always exerting a force towards collapse and expulsion of air, in the same way as the rubber balloon in the figure. The ribs fall back from their raised position, pressing air out of the lungs, almost entirely by virtue of their own weight.

It is of importance to notice what happens in the pleural space during these movements. The pleural cavity lies in the thorax round the lungs, so when the diaphragm descends, a vacuum or negative pressure is set up at once and increases with the depth of the breath taken. Even at the end of expiration, with the diaphragm back to its original position, the pressure in the pleura remains negative. This is proved by the fact that if a hole is made through the chest wall, so letting in atmospheric pressure, the lung at once

collapses, for its natural elasticity is useless except in a vacuum. Again, compare the bottle and the balloon.

Sometimes it is necessary to collapse the lung for treatment of disease. A hole is made with a hollow needle and air deliberately let in as necessary until the lung is collapsed. Owing to the fact that the pleural cavities for each lung are separate, this does not affect the opposite lung, which now does the work of two.

So far we have described the mechanism for normal quiet breathing, of which every one is unconscious. But if, for any reason, breathing becomes difficult, many more muscles are brought into play, particularly those of the abdominal wall, until finally the picture of a man who is being suffocated is produced, with almost all the muscles of his body being used in the effort to breathe.

The number of breaths taken per minute is variable. An average rate is about seventeen, but this is very easily influenced by exertion; even standing produces an increase above the rate for lying down. Emotion, too, affects the breathing very easily—witness the "heaving bosom" of distress, and we have all heard of people being "suffocated" by great emotion.

WHY A DOCTOR TAPS YOUR CHEST

When a doctor examines your lungs, after noting the shape and movements of the chest, he often taps with one finger, usually striking a finger of the other hand laid on the chest wall. This is known as percussion of the chest. The "note" produced by the blow of one finger on the other is normally rather like that of a muffled drum, owing to the hollow nature of the chest contents. This note is altered if there is disease beneath and the lung has become solid with inflammation, as in pneumonia, or the pleural space has filled with fluid, as in pleurisy.

Percussion is a valuable method of examination, therefore. It has rather a strange history. In 1761, a physician of Vienna, named Auenbrugger, published a small book on percussion, being "the fruits of seven years' observation and reflection." In his preface he noted that "it has always been the fate of those who have illustrated or improved the arts and sciences by their discoveries to be beset by envy, malice, hatred, detraction and calumny." It was a long and true list of the misfortunes of pioneers, but he left out the worst misfortune of all—indifference. This fate overtook Auenbrugger's book. None of the famous physicians of his day envied, maligned nor hated him. They ignored him utterly. He was forgotten until Corvisart, Napoleon's physician, translated the book in 1808, one year before Auenbrugger died. Percussion has been used all over the world ever since.

The other simple method of examining the chest, which also required a genius to discover it, was listening to it. If the ear is

out to the chest wall, or a stethoscope is used, each breath is heard ike a rustling of small leaves, due to the lung alveoli opening up to eceive the air. If you listen directly over the windpipe this sound s quite different, having a hollow blowing sound like a whispered ' ha "—this is known as " bronchial breathing." If it is heard over he lung it means disease. All kinds of variations in quantity and uality of the sounds are heard, and each has its special significance.

The stethoscope was first used by Laennec, a physician of Paris, vhen, failing to hear much in a fat patient by applying his ear to he chest wall, he took up a sheet of paper, rolled it into a tight roll nd applied one end of it to the chest over the heart, laying his ear o the other end. This was the first stethoscope.

HOW THE AIR WE BREATHE IS WARMED

Now let us turn back to the other problems of respiration. Earlier n, we mentioned that not only must air be drawn in but it must lso be made fit to enter the delicate lung tissues. First it must be varmed : this is largely the function of the nose, which has structures pecially designed for this purpose. As the air is drawn in, it is assed over large, rounded, bony shelves (the *turbinate* bones) which roject into the nasal cavity. These are covered with spongy blood essels which throw out their heat, so warming the air that makes ontact with them, just as a radiator heats the air around it. For his reason when air reaches the pharynx it is already quite warm nd does no injury. Compare this with the case of a " mouth-reather " where cold, unfiltered air is brought straight into contact vith the delicate throat membranes.

NATURE'S AIR FILTER

The nose also plays a large part in filtering out the dust particles f the air. This it does in two ways. You may have noticed the ttle hairs that obtrude from the openings of each nostril. These airs form a ring around the entrance or vestibule of the nose, so ltering off the dust from the incoming stream of air. Some dust, f course, gets past this first line of defence. This is dealt with by ie cells which line the cavity of the nose, covering the turbinate ones. Some of these cells secrete a sticky, slimy fluid (mucus). Dust sticks to this like flies to a fly-paper. If, however, the dust is ery plentiful—as, for example, in a fog—it may penetrate right own to the bronchi before being arrested. From here it is carried way by lymphatics, into lymphatic glands situated where the achea divides into the two bronchi. Some of it may, however, ay in the lung tissue.

Thus, though we are all born with pink lungs, in those of us who end our lives in large towns and smoky atmospheres, the lungs are ottled and streaked with black. This, however, does not harm us.

Other cells in the nose and trachea have long cilia attached. These neat processes are so designed that they move together in waves like the oars of a Roman galley, sweeping foreign material such as dust particles towards the surface of the body. Thus, some particles are swept to the opening of the nose, others are swept up the bronchi and trachea until they come to lie on the sensitive portion at the upper end, just below the voice-box. As soon as any quantity of this phlegm collects one feels a tickling sensation in the throat, a desire to cough, which results in the expulsion of foreign matter as *sputum* (pron.: spewtum).

WHY AND HOW WE COUGH

Coughing is a complex act. First a deep breath is taken, then the glottis closes, and expiration commences. But owing to closing of the glottis and the block so formed, no air is expelled; the pressure in the top part of the trachea is, in consequence, very considerably increased. Suddenly the glottis opens, permitting a quick release of air which carries with it the sputum which originally gave rise to the whole cough reflex. The noisy " bark " of a cough is due to the vocal cords in the larynx vibrating as the air rushes over them.

Sneezing is a very similar reflex designed to clear the nasal passages. Sudden expiration through the nose is the essence of it.

Having warmed and filtered the air, the body is faced with the problem of adjusting the water vapour it carries. This is very simply performed by the mucus secreted on the mucous membrane of nose and windpipe. Thus moisture is provided which will evaporate if dry air is drawn across it—but not if it is already moist.

ARTIFICIAL RESPIRATION

A proper understanding of the mechanism of respiratory movements should make it easy to grasp how to perform *artificial respiration*—knowledge that may often save lives. Artificial respiration is vital after such accidents as apparent drowning or electrocution, and should be persisted in for some four hours or longer.

The commonest method is that described by Schafer. The subject is placed on his belly, with the face turned to one side (as in Fig. 6). The operator kneels astride the subject's thighs, placing the palms of the hands each side on his lower ribs. Keeping the arms straight, not bent at the elbow, the operator swings his weight forward, so compressing the subject's ribs and expelling air from his lungs. Then he swings back to the first position again, keeping up a rhythm of about fifteen times a minute—the respiratory rhythm—so that each complete swing to and fro takes about four seconds.

Of course, it is important to keep the patient as warm as possible and to persist until he is breathing well again and is conscious

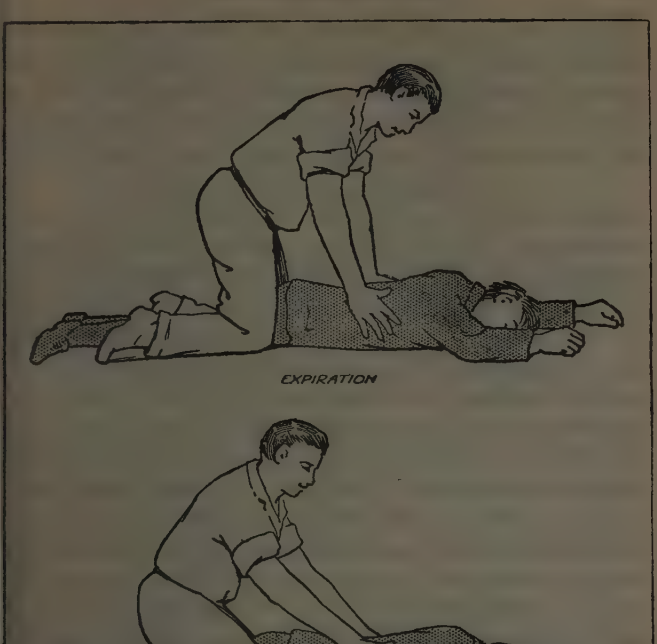


Fig. 6. Illustrating two positions in Schafer's method of artificial respiration.

Perhaps most important of all is the fact that a few minutes' artificial respiration given *early* is worth hours of it given later. So that if torn between the desire to call a doctor or do artificial respiration, decide on the latter.

So far, we have limited our description to the mechanism of taking a single breath. But this breathing has to be regulated in depth as well as rate, so that it serves the purposes of the whole body.

Like every other function in the body, the respiration must be integrated. The complexity of a single inspiration is astonishing enough. A stream of impulses is sent along the nerves to the nose,

along the vagus nerve to the larynx, along various branches of nerves to the neck muscles, along the nerves to the intercostal muscles, and along another nerve to the diaphragm. All these impulses have to be correlated so that each muscle does its part in aiding the others. Not only this, but all muscles whose contraction would impede the process must be inhibited. This is a wonderful procedure, but it does not touch on the great problem of control of respiration.

OUR CONTROL OF BREATHING

When we discussed the regulation of blood pressure and arterial movements we described how they were regulated by a "centre" in the part of the brain called the medulla oblongata. In the same part of the brain is a similar centre for regulating the breathing. But whereas the heart will go on beating at its own rhythm if separated from the vasomotor centre, the lungs will not go on breathing. They are entirely dependent on this nervous control. So that if the medulla oblongata is destroyed, breathing stops. These centres must, of course, have connections with all the parts of the respiratory apparatus in order to control them. This they have in the form of all the nerves mentioned in describing the complexity of the respiratory act in the previous paragraph. Most important of these are the vagus and *phrenic* nerves. The latter control the diaphragm.

Like the vasomotor centre, the respiratory centre is very sensitive to impulses reaching it. These most often come from the vagus nerve which arises in the region of the respiratory centre. But impulses may also come from the brain and many other parts.

Like the pace-maker of the heart, the respiratory centre has the curious capacity of originating rhythm. To any stimulus it always responds in a rhythmic manner. Presumably, the cells composing it have developed this capacity for rhythm to an exceptional degree.

CHEMICAL STIMULI FOR BREATHING

Just as in the case of the vasomotor centre, two main ways of stimulating the respiratory centre exist—the primitive chemical and the finer nervous influences.

Of the chemical substances, the most important again is carbon dioxide, which, when dissolved, forms carbonic acid. Lactic acid, formed by muscular exertion, is another. In fact, any increase of acids in the body will stimulate the respiratory centre, so that breathing becomes deeper and more frequent. Now since we have seen that carbon dioxide is formed in all tissue activities, breathing will become deeper if anything either increases its formation or in some way obstructs its being expelled through the lungs.

Lactic acid formed chiefly on muscular exertion explains in part the quicker and deeper breathing that accompanies exercise. On the other hand, if the carbon dioxide is washed out of the blood the

respiratory centre may fail to be stimulated and so no breath will be taken until sufficient has accumulated in the blood to stimulate it. Strangely enough, the respiratory centre is nothing like so sensitive to a lack of oxygen in the blood supplied to it; so insensitive is it that a man may lose consciousness from being deprived of oxygen before much disturbance of respiration occurs.

Now in exercise carbonic acid is produced. This is carried to the lungs where some of it is expelled, but not all, since an excess has been produced. The remainder finds its way to the respiratory centre and, as some hold, to a sensitive spot in the neck artery. Here stimulation causes deep breathing, an activity which washes out the carbon dioxide from the lungs and enables more to flow in from the blood. In this way any excess of carbon dioxide is quickly disposed of. Such is the neat chemical adjustment in the body of muscular activity and breathing.

THE NERVOUS REGULATION OF BREATHING

But there is also the nervous regulation of breathing, chiefly by the two vagus nerves. When a deep breath is taken the little air sacs of the lung are stretched. This causes stimuli to pass up the vagus nerve to the respiratory centre, whence impulses are sent out to stop this stretching; that is, to stop inspiration and commence expiration. So the diaphragm rises back again, the ribs sink, and the elastic bags of the lungs collapse. But when they have collapsed to a certain degree, fresh stimuli pass up the vagus again to the respiratory centre, this time conveying a different message. Again the centre sends out impulses to the breathing apparatus, this time to stop the collapse of the lung; that is, to commence inspiration. This goes on until the air sacs are stretched again when the whole cycle recommences.

We noted that stimulation of other nerves might affect the respiratory centre. Perhaps the best example is a general stimulus of cold from the skin, as when one plunges into a cold bath. At first the breath is involuntarily held, later it becomes deeper and slower than before.

When you breathe consciously, impulses from the brain are influencing the respiratory centre. If you deliberately breathe in and out as deeply as you can, you will soon blow out of your lungs the carbon dioxide, so that this substance becomes low in the blood and is not present to stimulate either the vasomotor or the respiratory centre, with the result that you will feel faint from derangement of blood supply and stop breathing for some seconds from failure of the respiratory centre to work until the carbon dioxide reaccumulates.

If you are fond of unpleasant experiments, this is a very easy and interesting one to perform—but do not do it too enthusiastically.

The opposite experiment is to hold your breath. The average

time possible for most people is about a minute. While you hold your breath, carbon dioxide is accumulating in the blood. In the minute, fifteen breaths'-worth, at least, of carbon dioxide have been kept in the body. This acts more and more on the respiratory centre which sends out stronger and stronger impulses to the diaphragm and chest muscles, until " breaking point " comes.

WHAT IS " SECOND WIND "?

We have all experienced the welcome sensation of " getting our second wind." This curious event is found to coincide with a marked fall in the amount of carbon dioxide in the lung as well as in the amount of air breathed. At this time also the temperature of the body rises suddenly and sweating begins; the body has struck up a new equilibrium adapted to the steady exertion, so that one can now go on running indefinitely.

What effect will changes in the air breathed have on respiration? This question is becoming more important than ever nowadays, not only from the point of view of the mountaineers on Everest, but from that of aviators.

If carbon dioxide is increased in the air around us there is at first very little effect on breathing. Almost certainly, the carbon dioxide in ordinary rooms never rises to a degree sufficient to disturb anybody. Normally, it is in air to the minute extent of 0·05 per cent. In expired air it is present to nearly five per cent. No effect on respiration is produced until it reaches about four per cent in the air breathed. This kind of thing only happens in caves and coal mines, particularly after an explosion when it forms the " choke damp." Since it is heavier than air, it lies on the ground; and canaries in cages used to be carried to detect it, since being lower they would suffer before their carrier.

DO WE LIVE ON OXYGEN?

As regards alteration of the oxygen in the air, we have already noticed how little lowering of the amount in the air alters breathing. Increasing the amount also has no effect, for at ordinary atmospheric pressure the hæmoglobin is saturated so that it can take no more. Increasing the amount in the air, therefore, will not increase the amount in the blood. This reasoning does not apply, however, where there is heart and lung disease.

At great heights, as in mountaineering or aviation, the atmosphere is much thinner and so exerts much less pressure. At about sixteen thousand feet atmospheric pressure is only half what it is at sea-level. In consequence, less oxygen enters the blood to combine with the hæmoglobin. The breathing, therefore, becomes deeper and more rapid, particularly on exercise. This washes out the carbon dioxide, unfortunately so reducing its action on the respiratory centre.

The muscles become weak from lack of oxygen, the breathing difficult, and headache, even mental changes, may develop. The heart particularly suffers from the deficient oxygen supply. This is "mountain sickness." But "acclimatization" makes a lot of difference, and at moderate heights may be perfect. The heart and tissues get used to the lower oxygen tension, while the permanent lack of oxygen stimulates the bone marrow, turning out more red blood corpuscles, which can carry more oxygen even though they are unsaturated.

Even at the height of nearly twenty-seven thousand feet reached by Mallory in the expedition to Mount Everest, the party were breathing ordinary air. Oxygen inhalation from a cylinder is resorted to usually at these great heights, but many people find it more uncomfortable than the rapid breathing necessary in the open air—and the cylinders are of necessity heavy, which detracts from their value to a mountaineer. At these heights, so great is the oxygen shortage that several breaths have to be taken for each step forward—such are the difficulties of pioneers.

WHY WE GASP AT HIGH ALTITUDES

For altitude records in aviation the problem is even more difficult, for at fifty thousand feet atmospheric pressure is only about one-ninth that at sea-level. Both mental and physical states are affected at heights above eighteen thousand feet, and to fly an aeroplane both are very necessary, so the partial pressure of oxygen must be increased. This may be done at first by increasing the percentage of oxygen, but after about forty thousand feet even pure oxygen at the diminished atmospheric pressure is not enough, and so the man must be put in an airtight suit and oxygen pumped in at an increased pressure—that is to say, higher than that of the atmosphere at forty thousand feet. By this means the pure oxygen is kept at a sufficient pressure to enable the pilot to retain full control of his strength and his judgment. This suit—rather like a diving suit to look at, though built for exactly the opposite circumstances of pressure—was used by the British airman who reached fifty thousand feet in 1937.

But the atmosphere may be altered in other ways. With divers, and workers in caissons under water, the pressure of the atmosphere is increased. This makes the nitrogen always present in the blood and fat tissues dissolve in greater degree. If now the caisson worker comes quickly to the surface, and ordinary atmospheric pressure, the nitrogen bubbles come out of solution, just as the gas in a ginger-beer bottle does when released from the high pressure inside to ordinary atmospheric outside. Now nitrogen in the blood cannot be used up, as it is so inert, and the tissues have no use for it, so that it flows in the blood vessels until it makes an "air lock" somewhere,

so depriving some organ of blood. It may thus cause paralysis if the brain is affected, and various other unpleasant effects which are known as " caisson disease."

To prevent this, the caisson workers are put into decompression chambers where the alteration of pressure is carried out at a slow, measured rate, with safety.

WHAT IS ASPHYXIA?

What do we mean by the word *asphyxia* (pron.: ass-fiksy-a)? We are now in a position to see that this term applies to any condition where the body is deprived of its necessary oxygen. If an animal is so deprived, there are three stages of suffocation until death ends the scene. First there is an attempt to over-breathe; gradually the force of the attempts at breathing increase until the stage of convulsions sets in. Here consciousness is lost and the whole body enters into violent movement, until suddenly the struggle is given up and the victim lies passive and limp, occasional deep gasping respirations breaking the appearance of death. These gasps become ever less frequent until at length the last breath is taken.

All these stages are caused by the accumulation of carbon dioxide in the respiratory centres, with the lack of necessary oxygen to keep the cells alive.

So asphyxia can be produced by anything which prevents the centre from getting its oxygen, whether by pressing on the throat or smothering, or by giving an atmosphere of carbon dioxide to breathe. Even carbon monoxide and prussic acid poisoning act partly by depriving the centre of oxygen, and so are forms of asphyxia. In drowning, water fills the lungs, instead of oxygenated air, so that death is asphyxial in nature and goes through the three main stages described.

HOW ANÆSTHETICS WORK

Asphyxia, strangely enough, forms a large element in the mechanism of some anæsthetics. An inhalation anæsthetic is a gas which produces unconsciousness. The first of these to be discovered and so frequently used by dentists was what is now spoken of as " gas." This " gas " is nitrous oxide, an inert substance that, when inhaled, interferes with oxidation in the cells of the body, particularly in the brain. Whilst this is going on, the patient goes through what is known as " the excitement stage " similar in many respects to the second stage of asphyxia. It is during this stage that, with this particular gas, the patient often has vivid dreams and sometimes roars with uncontrollable laughter—so giving nitrous oxide the name " laughing gas." It is this stage, too, which gives the anæsthetist trouble, for during it the half-conscious patient may struggle and fight—he is almost literally " drunk " with the gas. After this a

stage of quiet deep breathing occurs, during which a minor operation can be performed, the patient being unconscious. But long anæsthetics cannot be given with gas unless oxygen is combined; then, with the right balance of gas and oxygen, the anæsthetic can go on indefinitely. But it is just this balance which needs all the skill of the anæsthetist. Though it may sound rather alarming to say that gas anæsthesia is partial asphyxia—the fact is that it is perhaps the safest of all anæsthetics, for there are emphatic warning signs if the dose is getting too much for safety, and these are never overstepped.

Other anæsthetics such as ether and chloroform, act more by intoxicating the nerve cells of the brain than by depriving them of oxygen.

BREATH AND VENTILATION

The last problem in everyday life concerning respiration is that of ventilation. It is well known that in a crowded room one feels discomfort due to "stuffiness." What exactly is the cause of this? It is found that it is not due to an increase of carbon dioxide in the air of the room, for that may increase up to four per cent without causing any symptoms, and except under conditions resembling those in the "Black Hole of Calcutta" these are unlikely to arise. Nor is it due to oxygen lack. Leonard Hill, an English physiologist, did experiments to find out the essence of stuffiness. In one, of great ingenuity, a man (A) was kept in a small airtight room until he could stand it no longer. He was now allowed to poke his head through a sheet of rubber and breathe the "fresh" air outside, whilst another person (B), standing in the fresh air, put his head through a slit in another sheet of rubber, breathing the used air. The first man (A) got no relief at all whilst (B)

Fig. 7. How the vocal cords are examined.

did not find the used air in the small room at all discomforting. This experiment shows that "stuffiness" has less to do with the air breathed than with the capacity of the body to regulate its temperature.

In the chapter on the skin, we mentioned how body temperature was largely regulated by sweating, and skin capillary circulation. Here we see this verified, for if this process is made difficult, discomfort arises. The moisture of the air around, its temperature, and whether it is moving or not, are the properties which make for comfort or discomfort, not the amount of carbon dioxide which it contains.

In practice, ventilation should be arranged so that each person has one thousand cubic feet of space to himself, and the air should be moving. In this way it is renewed frequently: the individual should get two thousand to three thousand cubic feet per hour.

At the top of the windpipe is the larynx, or voice-box, containing the vocal cords (Fig. 7). These, with the pharynx, and the resonating chambers in cheeks and nose called the *sinuses*, form the apparatus for voice production. The larynx is like a box. Stretched across it on each side are the two reed-like vocal cords. These are so attached at each end that they can be drawn together or separated, loosened or tightened up. The chief nerve to the larynx is from the vagus. By a special mirror, the *laryngoscope*, the larynx can be seen. A drawing of what this mirror reveals is seen in Fig. 8. The back of the tongue is seen at the top, with the leaf-like epiglottis behind. The vocal cords stretch like two shining blades backwards (remember that in a mirror they appear back to front).

Fig. 8. The vocal cords as seen by the mirror in Fig. 7.

When we speak we first adjust our vocal cords approximately, and the voice sound is produced by air rushing between and so vibrating them. Voice sounds vary in pitch, loudness and quality. Pitch is represented, for example, by notes on the piano-scale; it is determined by the length of the cord. Most people can cover two octaves. Children have high-pitched "piping" voices because their vocal cords are short since they are housed in small larynxes. At puberty in boys the larynx grows very rapidly, the vocal cords get longer, and the voice "breaks." If the elongation of the cords is marked, a "bass" voice is produced; if less, a tenor.

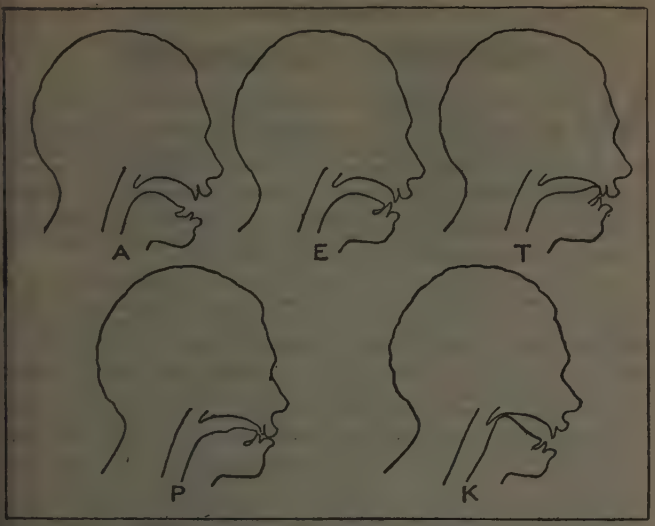


Fig. 9. How some letters are pronounced. Note the positions of lips, teeth and tongue in relation to one another.

In women this elongation does not occur, so the voice retains its higher pitch. In singing, three registers are recognized—head, middle and chest registers. Deep notes are from the chest, the whole vocal cords vibrating, whilst the high notes of the head register vibrate only the thin inner edges. Loudness depends on amplitude or extent of vibration. This is dependent on the strength of expiration; in shouting, a strong blast of air vibrates the cords to their utmost.

Quality of voice depends on overtones, and added vibrations known as harmonics—these are produced in resonating chambers such as the pharynx and sinuses. These chambers are, therefore, largely responsible for the difference between our own voices and Caruso's.

Words are formed from the sounds made in the larynx by altering the shape of the mouth cavity above. Vowels are all produced in this way, consonants by interrupting the flow of air, either at the lips, teeth, or at the back of the palate, as in p, t, and k, respectively. If you say these letters aloud and follow the diagrams in Fig. 9 you will be able to prove it for yourself.

CHAPTER VIII

NERVOUS TELEGRAPHY

WHEN we described an amœba, we noticed that it possessed in its small self all the attributes of life, such as excitability, the power of passing on stimuli and the ability to contract. These various attributes become separated, and highly developed as the properties of special tissues, in animals such as man. Muscle cells, for example, become specialized in the function of contracting, and nerve cells become mechanisms for picking up and transmitting messages—a central-telegraph system of the body.

As the body developed into its various organs and tissues, there arose the necessity for linking up these various parts into a unified whole. What would happen to a muscle, deprived of messages from the central co-ordinating centre? Though it might remain perfectly healthy, it would not know when to contract or relax—it would soon introduce a tragi-comic set of movements on its own, and hopeless confusion would spread through the rest of the body.

Always, there have existed in the body, as we have seen, two main methods of obtaining this co-ordination or integration of the body —chemical and nervous. The chemical methods developed first in primitive animals, and in certain cases have persisted still in man. But for chemical messages to flow round the body, time is necessary, and during that time the threatened danger may have acted

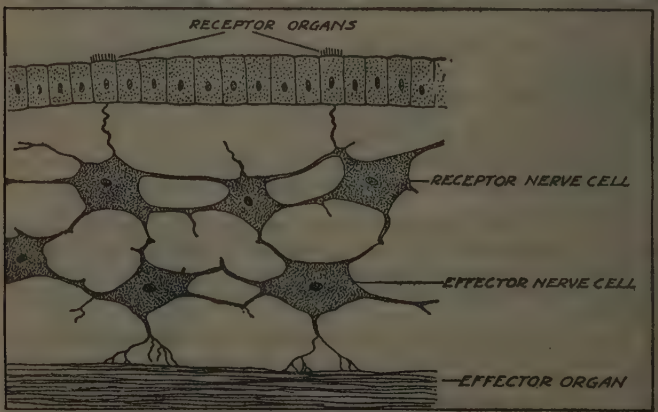


Fig. 1. A primitive nervous system, showing the simple relation between muscles (effector organs) and nerve endings.

So a quicker mechanism was necessary. This mechanism is the nervous system.

In its simplest form, the nervous system consists of the specialization of a surface cell to be sensitive, and responsive to changes of the environment. Such changes are known as stimuli.

But this limited field of response is not of much use to an animal as a whole, even where the sensitive cell connects directly with a muscle, for the response is only local. Gradually, therefore, a "receptor" apparatus for receiving stimuli and an "effector" apparatus for responding are separated off from the more primitive cell which possessed both (Fig. 1).

EVOLUTION OF THE NERVOUS SYSTEM

We have seen in Chapter IV how the skin combines defence with sensitiveness, and becomes the largest sensory organ in the body. Sensory receptor organs developed first in the surface layers of animals, then migrated below the surface, making extensive connections with one another and, finally, sending off fibres to act on a layer of muscle. Any small stimulus, therefore, set the whole apparatus going. Such nervous design is seen in animals like sea anemones.

We have described in Chapter II how the brain has developed at the front of a tubular animal and how this brain controls by nerves the nervous system. This necessarily means that the power of inhibition must develop in the nervous system, for one stimulus, demanding one thing, may well come from some particular section, whilst the brain sends a contradictory message, so that the first stimulus is inhibited and not acted upon, just as a soldier on parade inhibits, by his brain action, a desire to scratch his nose. Then lastly, in the development of the nervous system, came the power to remember the past. This capacity coincided with a fresh budding of the top of the brain called the *cerebrum* (pron.: ser'r-e-brum).

WHAT A NERVE CELL IS LIKE

In man the receptor cells, such as those we have already seen in the skin, are prodigiously prolonged, running through the body as nerve fibres. This prolongation is one of the curious marvels of the body. Taking an amœba as a typical cell, we described it as perhaps, just visible to the naked eye, about the size of a pin-point. A nerve cell is like an amœba except that it gives off a thread of protoplasm that may stretch three or four feet. The effector cells, or *neurones* (pron.: new'-roans), are just as long.

The primitive pattern upon which the nervous system is built is the "reflex arc" (*see* Fig. 2). This consists of the path followed by a stimulus which affects first the receptor, by which it is carried to the spinal cord. Here it passes from the receptor neurone to the

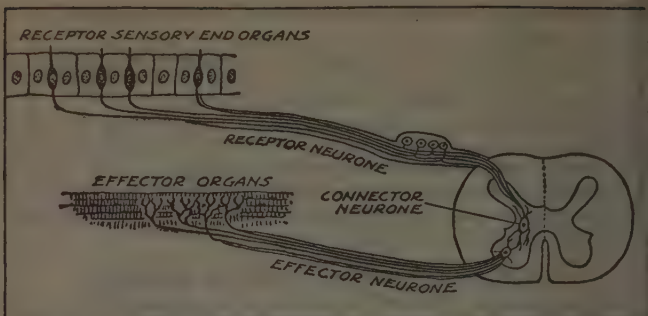


Fig. 2. Simplified illustration of the working of the reflex arc.

connector neurone. Of these there may be one or many. Finally the stimulus now emerges along the effector neurone, by which i is conducted to the effector organ, completing the reflex arc.

Reflexes are very important in human beings. Perhaps th simplest is the knee-jerk which we mentioned in describing the le muscles in Chapter III. Tapping the patella tendon stretches it this provides a stimulus for special receptors in the tendon, so tha impulses pass up the nerve to the spinal cord. Here they quickly pass through to the effector neurone, down which they flow and stimulate the muscle in front of the thigh to contract. This acts or the leg, jerking it forwards as in a kicking movement.

THE CENTRAL NERVOUS SYSTEM

So far we have seen, then, that the nervous system has developed from receptor and effector organs, has been subjugated, in large part, to the brain at the front end of the animal, and that the essence of its working is by the reflex. But there still stands out the fact that the main function of this system is integration. The nervous system has two rather different problems. Not only has it to enable the animal to react to situations of danger from outside, but it has to control the organs within so that they harmonize smoothly. For these two tasks there are two parts of the nervous system—the central or *somatic* and the *visceral* parts.

The central nervous system deals with the stimuli from outside, which most commonly end in muscular contraction such as movement—skin, muscle and joint sensation come into this part.

The visceral system regulates the state of blood vessels, intestines, lungs, heart and glands of the body. We have already seen how the vagus and sympathetic nerves work in relation to heart and lungs. They form part of the visceral system of nerves. In both

the reflex arc of receptor, connector, effector neurones is maintained.

Now, whereas our consciousness is continually being flooded in everyday life with impulses from the central nervous system, there is, in health (for most of the time), complete silence on the part of the visceral system except for the normal periodic feelings of hunger and a few other daily rhythmic acts. Some say that a definite sense of well-being is produced by this normal balanced visceral function.

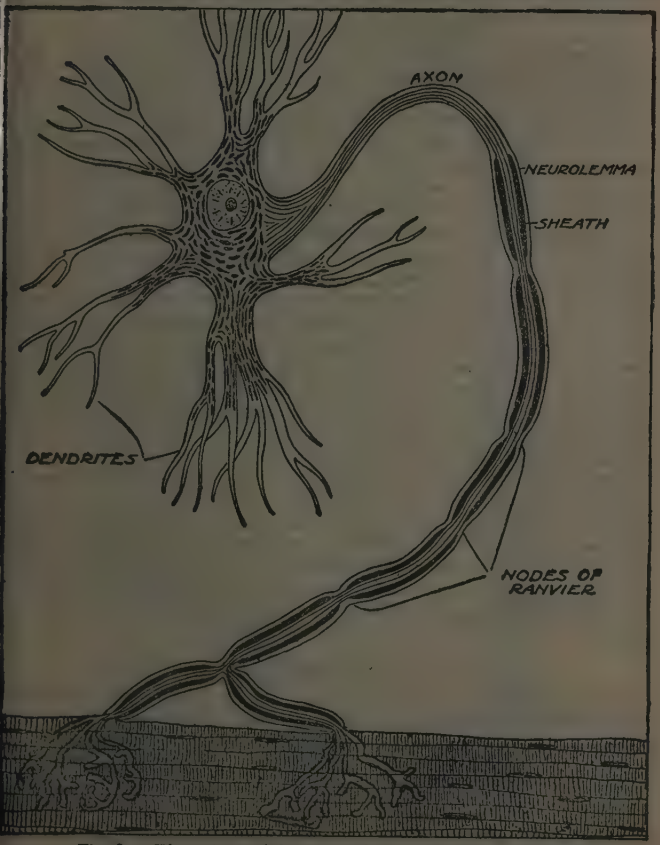


Fig. 3. The principal features of a nerve cell or neurone.

It is only when this balance is upset that we become aware of our viscera by means of pain and discomfort.

So these two parts of our nervous system supply us with all the material out of which our brains elaborate consciousness. From the patterns of impulses passing along the receptor nerves to the brain is built memory. From the patterns passing along the effector nerves from brain to muscle, arises behaviour.

THE NUCLEUS OF A NERVE

The cell unit of the nervous system is the neurone (Fig. 3). This consists of *axons* and *dendrites*. However long the axon (and sometimes it is some feet in length) its life and function depend on the nucleus of the cell. Most nerve fibres have around them a fatty sheath for protection and, maybe, electrical insulation from surrounding tissue. This sheath has on it a series of constrictions known as the *nodes of Ranvier*. Outside it is another thin sheath, the *neurolemma*.

Where one neurone comes into contact with another, the nerve fibres form *synapses* (pron.: sin-a'p-sees). These synapses are of great importance for they regulate the impulses that come to them by liberating certain chemical substances. First, for example, a synapse will permit the passage of an impulse in one direction only; that is, from the axon of one nerve to the dendrite of another. Secondly, it offers varying resistance to impulses so that it may even block out an impulse altogether. Thirdly, and equally important, is the variability of synapse resistance, for resistance of neighbouring synapses prevents a nervous stimulus or impulse from undue spreading, thus limiting its path to that desired. On the other hand, the repeated passage of impulses makes each one easier.

Most of the spinal cord and the brain is composed of connector neurones. With these it is vitally important that the above-mentioned properties of the synapse should be active, for otherwise any nerve impulse could spread all over the nervous system, with resulting un-co-ordinated responses of the muscles. This is what happens in a convulsion. When strychnine is given in poisonous doses it excites all the synapses, so preventing the correct regulation of the flow of impulses—with resulting spread and convulsions.

WHAT ARE NERVOUS IMPULSES?

But what are these "impulses" we mention? Nerve is a tissue specialized to excitability and conduction—these properties being selected at the expense of others such as a power to contract. If a stimulus is applied, there is a "change of state" brought about in the nerve. Excitability refers to the ease with which a stimulus produces this change of state, or impulse. When a nerve is stimulated, impulses stream up it. As the stimulus continues, however, the nerve fibre adapts itself to it, so that further responses are not

obtained. These impulses travel up nerve fibres at rates of as much as two hundred and fifty feet per second. When active, a nerve fibre uses up oxygen and gives off carbon dioxide in small amounts, just like other tissue.

The central nervous system as a whole can be most conveniently divided up into those parts conveying impulses towards the brain (the *afferent* system), and those away from it (the *efferent* system).

We shall first consider in a little more detail the receptor organs. These structures exist in skin, muscle and tendon. In the skin we have already seen them subserving temperature, touch and pain sense. In the muscle or tendon cells they form spindle-shaped structures, lying among the muscle fibres.

By special methods nerve impulses passing up single nerve axons have been amplified electrically millions of times, and records can be made of them. By this means the responses of receptor end organs to various stimuli have been worked out. In all, it is a similar story; there is a rhythmic response to a constant stimulus. The receptor always sends up discontinuous impulses—rhythmic streams of little waves of negative electricity. The more powerful the stimulus the more frequent the waves, sometimes as many as two hundred per second, but they never fuse into one.

Even receptor end organs, however, soon adapt themselves to stimuli, and impulses stop passing up the nerve. This adaptation is largely responsible for the curious way we become unaware of stimuli which are continually impinging on our skin—such as that from our clothes. Touch corpuscles adapt themselves very quickly. To pain and temperature, adaptation is less easy, but it occurs.

If a nerve in the arm is cut, and the ends sewn neatly together, the nerve fibres from the near end will grow down the opposite piece and eventually restore the lost sensation. But Henry Head, who first did this experiment, found that sensation

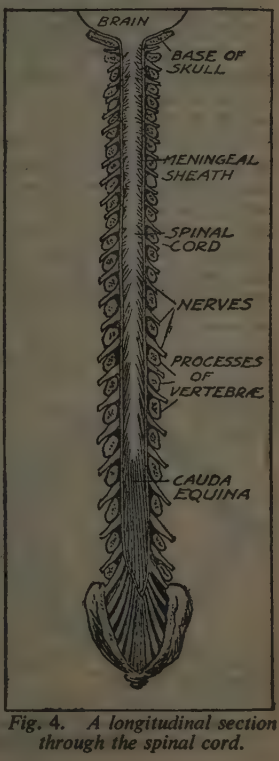


Fig. 4. A longitudinal section through the spinal cord.

came back in two stages. For after about twenty weeks capacit to feel pain returned, but without the ability to locate where th pain was. The pain of a pin-prick was peculiarly objectionable i character, and widespread. With temperature stimuli he coul detect no grading of warmth and coolness, only the extremes hot and cold. Later finer sensibility returned, and the sensations pin-prick and temperature became normal. Head drew the co clusion that there were two forms of sensation in the skin, the first primitive-feeling, and the second a finer discriminating sense.

STRUCTURE OF THE SPINAL CORD

The afferent impulses from these receptor organs, pass up to th spinal cord. This is a long worm-like structure of nervous tissu which runs from the brain, down almost the whole length of th spinal canal inside the backbone, wrapped in its coat of membrane the *meninges* (pron.: men-in'-jees) (Fig. 4). Its appearance when c across is seen in Fig. 5. In the centre is a grey portion aroun which the tissue is white. This central grey matter has two blu horns in front, and two pointed horns behind. It consists of a ma of nerve cells with their processes and supporting tissue. It is th many cell bodies which make it appear grey in colour, for the whi matter outside it consists entirely of nerve fibres. In this situatio the nerve fibres are collected into bundles subserving various se sations. They all travel up or down the cord to their particul destinations, some to complete spinal reflex arcs, some to cross th cord from one side to another, some to go right up to various par

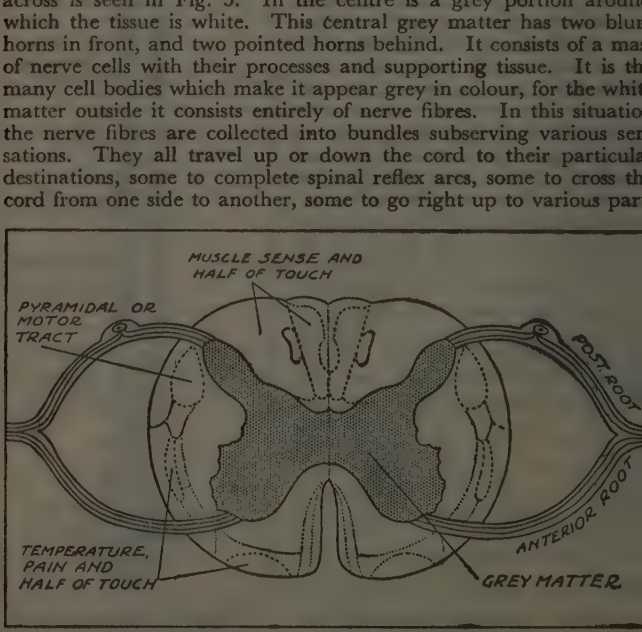


Fig. 5. A cross section of the spinal cord.

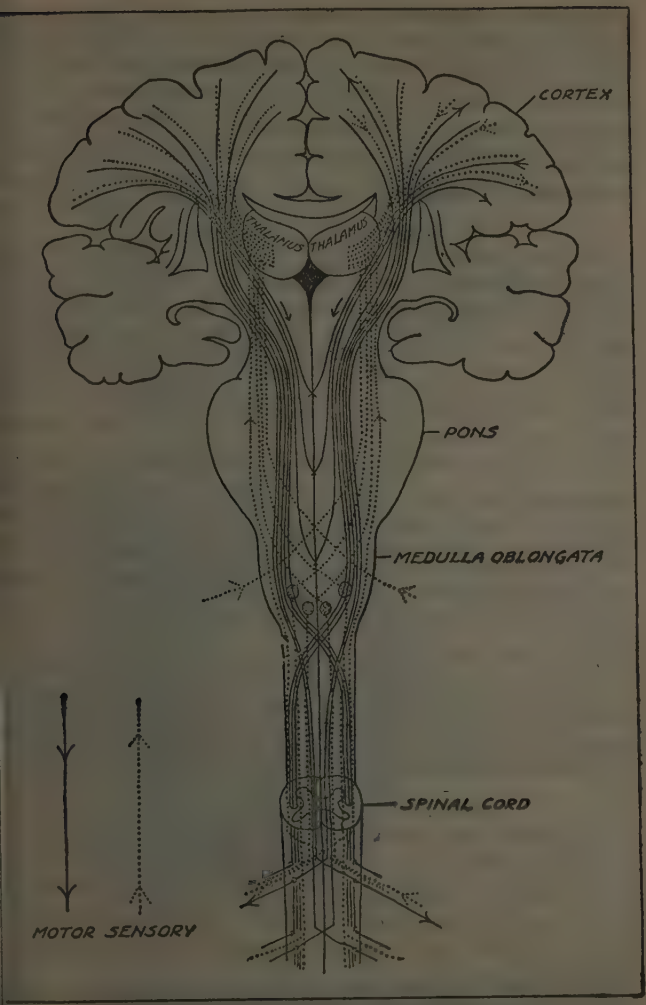


Fig. 6. The paths of the motor and sensory tracts.

of the brain. An almost indescribable medley of impulses going in all directions takes place in the small spinal cord, which measures less than half an inch across. But there is order in all this apparent chaos, though even yet we have many problems to solve.

Every axon or fibre in the white matter must have a nerve cell from which it came. The nerve cells of the afferent system with which we are at present concerned, lie outside the spinal cord or what is known as the posterior root. As the long axon from the sense organ in the skin runs centrally, it joins others to form a nerve

HOW NERVES COLLECT

This nerve continues on its course towards the spinal cord; it may contain a mixture of afferent fibres going centrally, and efferent fibres passing peripherally to the muscles. About half an inch from the cord these separate from one another, the sensory afferent fibres going to form the posterior root, the anterior bundle forming the anterior or motor root. From Fig. 5 you see that on the posterior root there is a rounded structure which contains masses of nerve cells. This is called the posterior root *ganglion*—" ganglion " being a word applied to a collection of nerve cells.

This is the cell whose peripheral process may have reached the skin some feet away. The central processes of these cells leave the posterior ganglion, pass centrally along the remainder of the posterior root to enter the cord, where they form part of the white matter we noticed above. The rest of the white matter is formed by tracts which run down from the brain to the cells of the anterior horn. Here they relay and produce motor neurones which pass out of the cord by the front roots, soon joining with the posterior root to form a spinal nerve.

This peculiar arrangement of nerve roots occurs in each segment of the body, as represented by each vertebra, the spinal nerves passing out between the vertebral bodies to their various destinations. The whole "segmental" division of nerves and vertebræ forms a very strong reminder that the human body is built up from a pattern whose foundations are portrayed in a worm with its ringed segmented body.

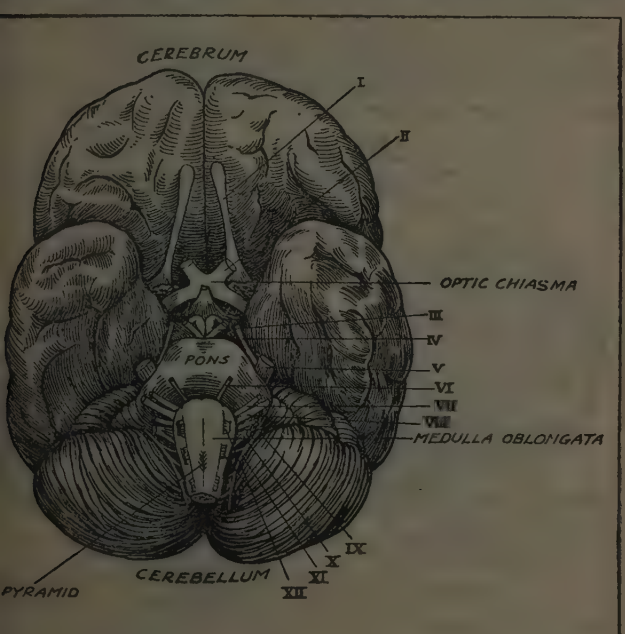
NERVES IN THE SPINAL CORD

In the spinal cord there is an arrangement of fibres according to the particular sense they serve. This remarkable device is shown in Fig. 6, where the ascending tracts are shown, on their way to various parts of the brain. All fibres bearing pain sensation are grouped together, touch fibres go in two bundles, and notice behind, a large collection of fibres carrying muscle sense, that is, sense of position and movement.

All these tracts, carrying various sensations, pass up in the spinal cord until they reach the medulla oblongata. Here some of the

urones end, and relay; others, pass on still farther to relay in the *ic thalamus*, a grey mass in the middle of the brain. Pain and nperature fibres cross and pass up the opposite side of the cord. nsations of posture and movement pass up at first on the same le, crossing later.

The pain and temperature fibres having reached the optic thalamus ay again, their final fibres going to the cerebral cortex. Fibres nveying sense of position and movement relay in the medulla, ne going on to the brain cortex, connections being made with the *ebellum*. It is because all the fibres bearing sensation cross to the posite side, that injury of the brain cortex on one side, e.g. left, oduces loss of sensation on the opposite side of the body, i.e. right. The medulla oblongata (*see* Figs. 7 and 8) is situated at the top the spinal cord. The small central canal of the cord opens out



. 7. *The brain from below, showing the cranial nerves.* (*For explanation of figures, see page* 196.)

into a space called the *fourth ventricle*. The grey matter which w saw in the spinal cord is now collected into grey masses. Thes form the so-called nuclei of special nerves to the face and head– the cranial nerves, as well as the respiratory and vasomotor centres which we have already mentioned. It can easily be imagined hov vital the medulla is, and that the slightest injury to it may be fatal

At each side of the ventricle, both above and below, tracts swee up into the roof, so forming the main connections with the cerebellum a part we shall discuss later.

THE "BRIDGE" OF THE BRAIN

The *pons* or "bridge," is the part of the brain just above the medulla It is named "pons" because it is the bridge of connection betwee both sides of the cerebellum, which are connected through it. Yo notice that the fourth ventricle runs behind it (Fig. 8), ending a the *aqueduct of Sylvius* which passes up into the third ventricle, throug a part known as the mid-brain, in which lie the grey nuclear masse for the cranial nerves which move the eyeballs.

At the top of the mid-brain are two bodies, about the size of walnuts

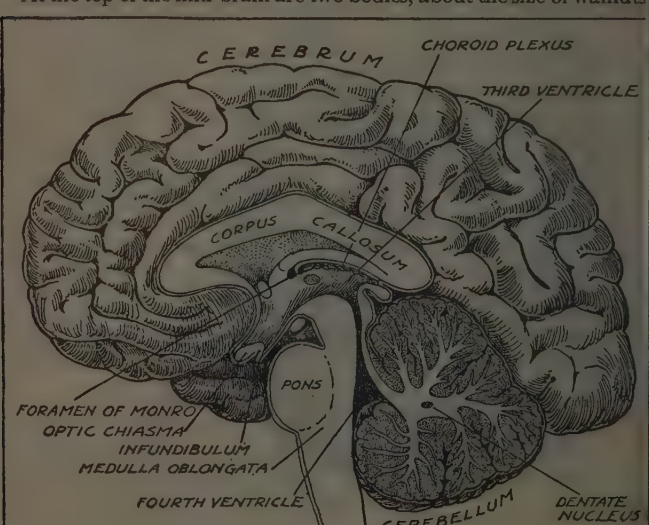


Fig. 8. *A section of the whole of the brain, showing the relation of variou parts.*

consisting of grey matter. These are the optic thalami. They form the side walls of the third ventricle. It is here that the pain and temperature fibres relay. The floor of the third ventricle is still a region of fascinating mystery. Right in front is seen the " crossing " of the nerve of sight, behind this, the stalk of the pituitary gland, the gland which secretes chemicals into the brain. Behind this there is the *hypothalamic* (which simply means, " beneath the thalamus ") region in which, of recent years, it has been suggested there lies the secret of sleep, and balance in the water.

Over the third ventricle you see a thick white hood. This is the *corpus callosum*. It is composed of masses of fibres connecting one side of the brain with the other, in the same way as the pons was the connection between both sides of the cerebellum. And yet if these fibres are divided (as has been done), there is little recognizable effect on behaviour.

HOW THE BRAIN IS PROTECTED

In front of the third ventricle is a small hole the *foramen of Monro*, which opens, on each side, into a large cavity in the brain—the lateral ventricle. In the roof of the third ventricle a thin veil, full of blood vessels hangs down. This, the *choroid plexus*, has the special function of secreting a fluid, which flows through all these spaces, or ventricles, we have just described, and covers the surface of the brain, so protecting it from the hard skull bones. It also flows right down the spinal column round the spinal cord.

Above the corpus callosum are folds of soft brain tissue, forming a mantle over all the parts we have just described. This is the cerebrum. Primitive brains consist of these grey basal parts we have just described, medulla and thalamus being the highest developed. But when mammals appeared, the part which was originally quite small, lying in front of these, grew rapidly upwards, and backwards so covering in the primitive areas, until the new human brain was formed.

THE VARIOUS AREAS OF THE CORTEX

In Fig. 9, you see the cortex divided into various areas according to their function. Running down the side near the middle is the large *fissure of Rolando*. In front of this is the origin of cells, which enable voluntary movements to be made in any part of the body. You see that the body is represented upside down as it were, except that face and hand areas are very close together. This is because of the existence of a literal " hand to mouth " existence of primitive anthropoids when their brains were developing.

Now in this area, large neurones exist in the cortex. The axons of these cells run first into the brain, pass the optic thalamus, and going down through mid-brain and pons, enter the medulla, where they cross to the opposite side, forming little prominences named

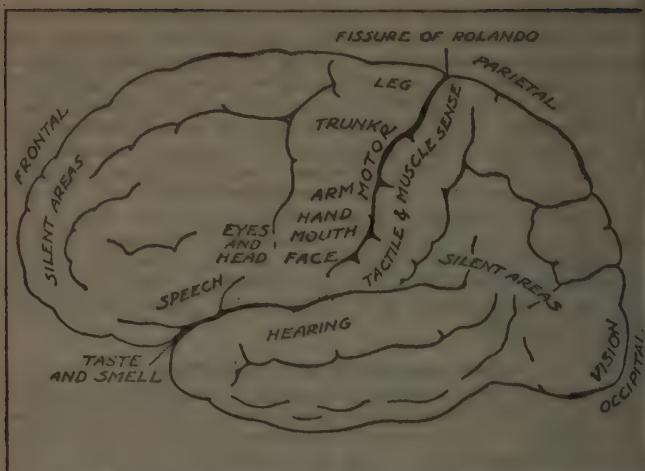


Fig. 9. A simplified drawing of the brain (cortex), showing the various areas in relation to bodily behaviour.

by the earlier anatomists "pyramids"—the fibres forming the *pyramidal tract.*

From the medulla, these fibres pass into the spinal cord, where we have seen them, before going to the anterior horn cells. All nerve impulses for movement of the body, travel along this course therefore—so that if the motor cortex, as it is called, is injured, or there is an injury or disease anywhere in the path, paralysis for voluntary movement will exist on the opposite side of the body.

WHAT IS A "STROKE"?

Exactly where, and how extensive this paralysis is, depends on the site of disease. In old people very often an artery near the course of these nerve fibres, bleeds. This results in injury to all the pyramidal fibres, for it so happens they are closely packed together in this region, and paralysis all down the opposite side of the body suddenly develops. This is apoplexy or a "stroke."

In the brain cortex, behind the fissure of Rolando, is the area in which end the sensory impulses brought by the peripheral nerves and relayed at the thalamus.

We have so far, then, seen how the nervous impulses of sensation and voluntary movement pick their complex way through the nervous system, from brain to muscle, or from skin to brain. But there are

further interesting points. For example, it is a peculiar fact that there are always three neurones concerned in this complete pathway—the only exception being in the case of the primitive sense of smell. Synapses occur first in the grey matter of the spinal cord, or at the top of the cord in the case of the sensation of posture and movement, again at the optic thalamus, whence the final neurone goes to the cortex. Why three? It is an unanswerable question.

SPECIAL FUNCTIONS OF OUR SENSE ORGANS

Another peculiar fact is, that however a receptor organ is stimulated, it always gives its own specific sensation. This is perhaps best illustrated in the special sense of vision. The optic nerve is sensitive to light, but suppose it is stimulated by a blow? Then it responds—not by pain or any other sensation because it cannot, but by sending to the brain a shower of impulses conveying the sense of light—so that one "sees stars." And again if you hit your funny-bone, the pain goes down and is felt in the little finger. There is a nerve here whose *normal* impulses come from the little finger. The impulses from the nerve at the elbow have therefore been interpreted by the brain cortex, as coming from the normal site—although our other senses tell us this is wrong.

The same reasoning applies to "ghost" limbs after amputation. The stimuli in the wound of an amputation stump, send up impulses along the nerves which previously carried impulses from the foot—so that the brain still "feels" the foot, although it is no longer there. Sometimes patients will not believe that their legs have been removed—until they are shown the stump.

HOW THE ARM IS BENT

We have described, as well as pain and temperature sense, the sense of posture and movement. At first sight it might be thought that muscles were designed for movement alone. But this is not so. In order to harmonize the movements of various muscles, there must be a mechanism by which some central control is kept informed of the various positions and movements, as well as issuing orders to them.

This function is extremely complicated and involves several different reflex arcs. The simplest is the spinal reflex we have already described in the knee-jerk—but as a movement becomes more complex, such as playing the piano, or riding a bicycle, amazing complexity of control comes in. Impulses from the anterior horn cells actually stimulate muscles, but these are not grouped to form a "movement" so that irregular twitching is all that occurs. For a co-ordinated movement to occur, it is not only essential that one group of muscles should contract, e.g., the biceps group to bend the arm, but that the antagonist muscles shall *actively* relax. It has been found that impulses to antagonistic muscles definitely inhibit their action, so

that in this example, the triceps become slacker in "tone." Th "tone" of a muscle is very important—it is by tone we adopt posture. If you sit quite still no muscle is actively contractin causing movement, but the position of sitting is maintained by virtu of slight activity, called tone. If stimuli causing loss of tone wer sent to these muscles, you would collapse in a heap in a postu regulated by gravity alone. Tone diminishes in sleep and und deep anæsthesia. In tetanus or lock-jaw, it is tone of the masset muscles that is primarily increased.

To return to bending the arm. The biceps contract. The tricep relax tone; meanwhile other muscles of the shoulder girdle steady th shoulder—contracting and relaxing as the movement of bendin requires it—a harmony of movement shown by the smooth, accuratel judged extent of the action, which is perfectly adapted to its goa

HOW WE CONTROL OUR MOVEMENTS

This smooth harmony depends not only on the afferent impuls from the muscle, but also on spinal cord, cerebellum, and even cortex- if we are making a "conscious" movement. These sensations pa up the spinal cord, where we have followed them, to the brain an cerebellum, enabling the vital regulation and control to take plac

We have said that the cerebrum is the newest and most develope part of the brain of man. It is interesting to reflect that whereas ma has developed his cerebrum, birds developed the basal ganglia—thal mus and similar parts, so increasing their capacities on different line

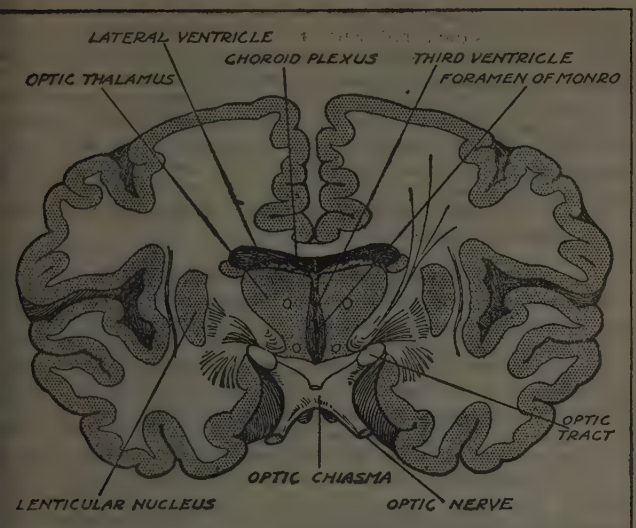
Both are parallel experiments in evolution.

The oldest part of the new-brain in man, is that adapted to smel This has become unimportant in the course of time, since man adopte the upright posture, and so became unable to put his nose to th ground where scent lies. It has dwindled and given way to the oth senses of hearing and sight.

THE CENTRE OF THOUGHT

The surface of the brain is split up by fissures into convolutions- thus increasing the surface area or *cortex*. This cortex contains th highest nerve cells of all whence, presumably, thought emanates.

The fissures divide the brain into regions. We have alread described the most important fissure of Rolando (Fig. 9). In th front of the brain are the frontal lobes. Here thought, and possibl morals reside. This area is however "silent," it can be injured- even destroyed as in a famous case where a crowbar pierced the sku of a man in this region, without producing any recognizable disabilit At any rate this particular man went back to work afterwards, an was just as efficient as before. On the other hand, with tumours an abscesses in the frontal region, patients often become extremel debased in their habits, sometimes completely changing the



g. 10. Simplified drawing of a horizontal section through the cerebrum.

ersonality. At the back of the frontal region, is the motor area e have described already. Behind the fissure of Rolando is the gion where sensation is registered and memorized. Here the ower of judgment of sensation lies. The capacity of balancing, mparing and measuring sensation is different from the sensation ure and simple, and lies in this region. The sense of recognizing hat is put into your hand for example, lies here. A person with sease of this part of the brain, knows that something has been put to his hand, but he cannot for the life of him recognize its nature. iven a half-crown he may call it a button.

Behind this region is the occipital lobe, where vision is registered. t each side is the temporal lobe used for hearing.

Every man's brain is different from his neighbour's, in just the me way as his face is. The folds and fissures have very variable rrangements on the ground plan. The two halves of a brain are ery similar, but not identical—a difference reflected in our bodies left- or right-handedness.

If a brain is cut across, as in Fig. 10, where a cut has been made in e coronal or side to side plane, the cerebral hemispheres are seen consist of grey matter on the outside—the opposite arrangement to

the spinal cord, where the grey lies inside the white matter. This grey rind contains the nerve cells. Inside is the white matter formed by the nerve fibres from cortical cells running in various directions, connecting up different regions of the brain, or running down to the spinal cord. Towards the centre are more grey masses. These are the basal ganglia, such as the optic thalamus, which we saw as the walls of the third ventricle which is seen here as a slit between them, passing above and on each side, into the two arms of a Y. These are the lateral ventricles. Running down outside the optic thalamus, but inside another grey nucleus, is the pyramidal tract, entering the mid-brain.

KEEPING OUR TEMPERATURES NORMAL

The basal ganglia are another area of fascinating mystery. In the optic thalamus we have seen sensory fibres relay before finally passing to the cortex, behind the fissure of Rolando. But the thalamus is thought to be capable of registering conscious sensation—of a crude type. Pain is sometimes produced in disease of the thalamus, of a peculiarly unpleasant, sickening nature—rather like the primitive sense noticed in the first recovery stage after cutting a nerve. The other grey masses near the optic thalamus, may have some part to play in rhythmic movement—for in disease of them rhythmic tremor forms a prominent sign. It is also in these grey masses that temperature regulation probably takes place. For in an experiment, a tube was passed to lie on this part of the brain. Cooling the water in the tube gave rise to shivering—a compensatory mechanism. Warming it did the opposite. Some hold, however, that the heat regulating centre lies in the floor of the third ventricle or hypothalamus. It may be that the thalamus is the seat of the emotions, love and hate—the driving powers of life.

THE CRANIAL NERVES

From the base of the brain, mid-brain, and medulla, come off twelve pairs of cranial nerves. These are numbered I to XII in Fig. 7. They are, in a way, merely continuations of the spinal nerves we have already seen coming off the spinal cord. But the grey matter has lost its regular shape, and there are so many other nerve centres and fibres developed at this end of the nervous system, that the primitive arrangement is grossly distorted. But one must not forget that in essence, just as the skull is derived from vertebræ, so is the brain derived from spinal cord.

The cranial nerves are as follows: the first is the nerve of smell. The nerve fibres rise from the mucous membrane of the nose, whence they run back as seen in Fig. 7 of the brain from below, ending in the primitive smell-brain.

The second is the optic nerve, which you see has been cut in Fig. 7.

The third, fourth, and sixth control movements of the eye. The fifth supplies sensation to face, teeth and meninges. It also supplies motor fibres to the muscles of the jaw. The seventh is the facial nerve, which supplies all the muscles of expression. The eighth is the nerve of hearing. The ninth supplies us with most of the pleasures of taste from the tongue. The tenth is the vagus of which we have already heard so much. This nerve not only supplies heart and lungs, but stomach and intestines as well. The eleventh supplies muscles of the pharynx, whilst the twelfth supplies motor fibres to the tongue, and so is responsible for the movements of speech.

Behind the main mass of the brain, is the cerebellum (Figs. 7 and 8). This organ consists of two side portions, with a wormlike mass between. Each half sends fibres through the pons to join its fellow of the opposite side. Like the cerebrum, the cerebellum reaches its highest development in man, being a primitive structure in lower animals. Cut across, it shows a folded outer rind of grey matter with white fibres within, and in the centre a core of grey matter.

If the cerebellum is diseased in man, then he cannot stand upright—bodily equilibrium is lost—muscle tone is quite out of control. The gait is that of a drunken man. There is also weakness, and if the right side of the cerebellum is diseased the patient falls down always on that side. There is also a marked tremor on that side.

FUNCTION OF THE CEREBELLUM

What is the function, then of this organ? It is concerned with the co-ordination of muscular movement and tone, which we described when we analysed movement of a limb. First the cortex suggests the movement and sends impulses down the pyramidal tract to the anterior horn cells. Now the cerebellum comes into control and performs the movement by harmonizing all the muscle forces as they work.

Take away the cerebellum, and clumsiness, inaccuracy and weakness blur the whole movement. To play its part, the cerebellum must have a good supply of nerves from muscles—which it has. It controls not only the limbs, but the eyes, tongue and lips in this way. It is the cerebellum that develops complicated patterns of movement such as riding a bicycle, so that what at first demands all one's concentration (cortical activity) after a few repetitions shifts over to the cerebellum, and becomes automatic or a habit, so that one can ride a bicycle without thinking. This development leaves the cortex free to think of other things, perhaps learning a new set of movements. As these sets of movements are learnt, their complexity increases, until we have the " trick riders " who can juggle on bicycles.

But balance requires another mechanism, as well. The brain receives a set of balancing impulses through the eighth cranial nerve. Deep in the substance of the temporal bone is what is called the

internal ear, part of which is devoted to the appreciation of positio of the head in space—whether tilted or straight for example, and als to movements of the head in all directions. We shall describe th mechanism more fully when we reach the ear, for the sense of balanc is almost a special sense. This part of the ear is intimately coi cerned with giddiness, and some forms of sickness.

WHERE WE STORE OUR MEMORIES

Let us now review what part the cerebral cortex plays wit regard to other parts of the brain. We have already mentioned tha it is in the cortex that the powers of memory, judgment and unde standing lie, as well as the initiation of movements and the appreci tion of relations between sensations—powers which lie near the fissu of Rolando. Consciousness itself goes if the cortex is destroyed i man, though this does not apply to other animals as strongly.

Perhaps as regards an animal as a whole, the cerebrum is s important for what it stops or inhibits, as for what it stimulates.

The cortex inhibits a spinal cord reflex, for the good of the anim as a whole—for example, reflex scratching or laughing may be s inhibited. That the cortical cells do inhibit spinal reflexes in som way, is proved by the fact that if the pyramidal cells are injure the knee-jerk (a spinal reflex) becomes exaggerated.

But the cerebrum also acts as a communication between a varieties of stimuli. Smell, sight and touch impulses are all closel connected up, so that their separate impressions can be compare and noted—giving a great opportunity for relationships to be di covered—and the discovery of relationships is the essence knowledge.

PAVLOV'S WORK ON REFLEXES

The cortex is necessary for the formation of "conditioned reflexes. This work was done by the great Russian physiologis Pavlov, on dogs. He divided reflexes into two types—the uncond tioned or inborn reflexes, such as salivation at the taste of food; th other, "conditioned" reflexes which are acquired in life. Pavlov dogs at first salivated only if food was put inside their mouth But if food was always accompanied by a bell ringing, then eventual ringing the bell alone was sufficient to cause salivation. Compa our own reactions to the gong at meal times.

By conditioned reflexes unconscious memories are built up—an actions based on these are called "instinctive."

The capacity to form these conditioned reflexes is presented in a new-born babes. Whereas their unconditioned reflexes such knee-jerks, etc., are already formed, the baby's brain is virgin sc as regards the conditioned variety. Formation of these is a large pa of education of an elementary kind. Now human babies a

immature for a longer proportion of their life-span than any other animal, so they have the opportunity to form more complex conditioned reflexes than any other animal.

But Pavlov probed further into the problem and found that the established conditioned reflex could be inhibited by various manœuvres. Eventually he established complex laws of stimulation and inhibition, which were dependent on the cortex of the cerebrum; for dogs with the cortex of the brain removed failed to establish conditioned reflexes. Finally, Pavlov describes consciousness as like a spot-light moving about the cortex of the brain—an area of activity amongst the surrounding shadows of inhibition.

REFLEX ACTION AND ASSOCIATION

The essence of the conditioned reflex is, then, an association of sensations. This has its anatomical counterpart in the association fibres in the brain. We mentioned that a large part of the white matter of the brain was built of fibres joining, in almost every conceivable way, different parts of the cortex.

A good example of this lies at the back of the frontal lobe on the left side of the brain. This part, in right-handed people is sometimes called the speech centre (Fig. 9), for injury here has a strange result. If an injury cuts the association path between the speech centre and the vision centre in the occipital lobe, then a man can see words and understand them, but he cannot read them out aloud—the connection between seeing and speaking movement of the tongue has gone. A parallel event occurs if the injury cuts the path from the auditory centre in the temporal lobe, then he can hear—but not repeat what he hears. The association paths so necessary for the conditioned reflexes underlying reading out loud or repeating a remark, have been destroyed.

WHAT IS SLEEP?

Sleep is a very curious event, so common that few of us trouble to think of it much. Tiredness may be produced in the muscles after exercise. But we all know of an equally urgent weariness even if we have done no muscular work during the day at all, but plenty of brain-work. This is a nerve fatigue, and in this condition many of the functions of the body are in diminished activity. This stage merges into that of sleep where the heart slows, respirations become slow, regular and deep, and muscles lose all their tone. Strangely enough, however, kidneys, skin, and intestines carry on their functions, with very little diminished energy.

Many studies have been made of sleep, and various theories suggested to account for it; none of them are really satisfactory. Pavlov suggested, on his conditioned reflex basis, that sleep was conditioned inhibition of activity spread all over the brain. He

actually induced sleep on his dogs by separating the interval between, for example, ringing of the bell and the food which followed. So that the animal entered an inhibited period very much resembling sleep, if an hour or so lay between the two events. According to Pavlov's view the nightly routine, undressing, emptying the pockets, washing, getting into bed, etc., is most important, as corresponding to the ringing of the bell in the case of the dog, and acting as a stimulus to cortical inhibition. Because we cannot do these things precisely the same way in another house, we often have difficulty in sleeping in a strange bed for a few nights, until our new routine is established.

WHY WE GO TO SLEEP

On the other hand, another physiologist has produced sleep by stimulating certain parts of the optic thalamus. The, as yet unanswered, question of whether the thalamus inhibits cortical activity arises.

Others suggest that sleep is due to a fall of blood pressure in the brain, or that the body creates chemical bodies which poison the cortical cells, so that they cease to function. If blood is taken from a fatigued animal and put into one that is fresh and rested, this latter becomes fatigued. Is there then, a chemical substance in the blood of the first that induces sleep? No one definitely knows.

On examining the brains of fatigued animals the nerve synapses have been found to be very thick and knobbly, as if contracted and separated from each other, so that some have said that sleep is due to increased synapse resistance. And lastly, the hypothalamic region has been associated with sleep, in that disease which destroys this region is often accompanied by unusual drowsiness.

Though sleep seems necessary, people vary enormously in their needs. Babies do almost nothing but sleep, waking only for food, and the very old need less and less sleep. An average adult needs about eight hours in the twenty-four. But there are reported cases of people who have not slept for weeks or months, without apparently suffering much harm from it. So sleep remains a fascinating problem—one of Nature's deepest riddles.

THE VISCERAL NERVOUS SYSTEM

At the outset of this chapter we divided the nervous system into two main parts, central and visceral, and we have so far limited our discussion to the former. The visceral system, so named because it comprises the automatic self-regulation of the viscera, is divided into two opposing, or balancing parts, the sympathetic and para-sympathetic systems. We have already met these two parts in the control of heart and lungs.

The sympathetic system is made up of a chain of so-called lateral

ganglia, running down each side of the vertebræ. Two or three of these ganglia lie in the neck region. Many lie in the thorax and can be seen in Fig. 8, page 127. showing the chest from the left side, giving off the splanchnic nerves which pierce the diaphragm to supply the abdominal viscera. In the abdomen the chain of sympathetic ganglia continues, lying on each side of the aorta, and extra ganglia lie on and around the aorta, amongst which is the network forming the well-known *solar plexus*.

All these lateral ganglia have connections with the spinal nerves. These connections are of two kinds. Small white fibres (Fig. 11), with medullary sheaths (taking their origin in what is known as the lateral horn of grey matter in the spinal cord), run out with the anterior root, which they soon leave to pass to the ganglion, and enter the sympathetic chain. Here they may run up or down for several ganglia, eventually ending round a ganglion cell. Fibres arising from this ganglion cell pass straight back to the spinal nerve, so forming the grey connectors. With this spinal nerve they run to muscles and arteries of the limbs, so controlling blood pressure, as we saw in Chapter V.

WHY OUR FIRST CIGARETTE MAKES US SICK

Now these white fibres flow out of the spinal cord only from the first thoracic to the third lumbar segments, so that they must spread up and down in a sympathetic chain to supply neck and head and feet. This they do, but the white pre-ganglionic fibre always relays to a grey post-ganglionic fibre before reaching its destination in the organ to be stimulated. This relay occurs in one of the sympathetic ganglia of the chain. It involves a synapse. It is on these synapses that the poison nicotine acts, so that the amateur smoker finds the nervous control of his stomach and intestines very much upset—with what dire results we all know.

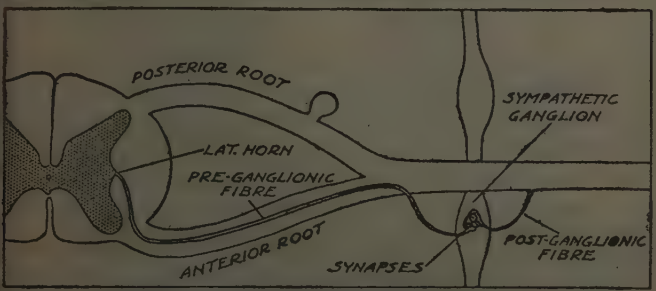


Fig. 11. *Simplified diagram showing the connections of the sympathetic nervous system.*

The parasympathetic system flows out of the nervous system (*a*) from the brain stem in the vagus nerve, and in the third and seventh cranial nerves; and (*b*) from the sacral region of the cord which supplies the viscera of the pelvis, and the genitalia. This system to a great extent antagonizes the sympathetic system in its control of organs.

Some structures are probably supplied by sympathetic fibres only such as sweat glands, and the small *arrector pili* muscles which we saw caused erection of the hair and "goose flesh." Most, however, have their supply from both sets. For instance, the pupil of the eye, is dilated by the sympathetic fibres, and contracted by the parasympathetic. The action of the two on heart and lungs we have already mentioned. On the gut, the sympathetic actions tend to relax the muscle coats, but to constrict the valves—the vagus or parasympathetic doing just the opposite. On the genital glands the sympathetic reduces secretion and activity, whereas the parasympathetic (via the sacral nerves) increases these.

HOW THE NERVOUS SYSTEMS CO-OPERATE

All through therefore, it will be noticed that the sympathetic enhances all those activities, such as muscle action of the body opening up the lungs for air, dilating the arteries of the heart, at the same time diminishing intestinal and sexual functions. The sympathetic system burns energy or is *katabolic*, whereas the vagus is concerned with the opposite, building up, or *anabolic* process.

The apparent antagonism is not present in reality, for both processes are essential to each other. How could the sympathetic system demand active burning of cell fuel, unless the parasympathetic had built up the fuel to burn? Just as sleeping and waking depend on each other, so do the sympathetic and parasympathetic nervous systems.

HOW ADRENALIN AFFECTS US

Cannon in America, has recently operated on animals, entirely removing the sympathetic system. What was the result? At first the animal appeared normal, but it was soon found that it had lost all its power of responding to changes of environment. It could not run far, it could not keep warm in a cold atmosphere, or cool in a hot one. It was not fitted for the emergencies of everyday life.

It should be noted here that adrenalin, the substance secreted from the suprarenal gland on top of the kidneys, has an action which exactly imitates that of the sympathetic in all its particulars. It is even thought, that the sympathetic system may act by releasing small quantities of adrenalin at the actual minute endings of the nerves in the organs which they supply. Cannon, however, calls this substance *sympathin*, and finds it differs in some ways from adrenalin.

The parasympathetic chemical liberated at the nerve terminals is a substance *acetyl-choline*, which can be collected from heart-muscle, after the vagus nerve has been strongly stimulated.

And lastly, one must remember the recently found hypothalamic centres in the floor of the third ventricle, which are said to influence, in ways as yet uncertain, temperature, urine, tears, and even the uterus.

The riddle of exactly how the nervous system integrates still awaits a full answer.

We cannot leave the subject of the nervous system without describing briefly the cerebro-spinal fluid and meninges.

THE CEREBRO-SPINAL FLUID

We mentioned that hanging in the roof of the third ventricle is a net of blood vessels. This extends also into the lateral ventricles on each side, and secretes a clear watery fluid into them—the cerebro-spinal fluid. This fluid then passes through two holes at the front end of the ventricle—the foramen of Monro—so reaching the third ventricle. Passing through this, down the *aqueduct of Sylvius*, it enters the fourth ventricle. At the back of this, two small holes permit its passage to the base of the brain below the cerebellum. Some of the fluid now passes down, outside the spinal cord, between it and the meninges, most, however, sweeps up over the surface of the cortex on each side to the midline above, where it is absorbed into a large vein, so re-entering the blood stream which it left by way of the choroid plexus (Fig. 10), in the lateral ventricles.

WHAT ARE THE MENINGES?

The meninges are three coats of fibrous tissue, in which the brain and spinal cord are wrapped. When they become inflamed meningitis is the result. Sometimes, as a result of inflammation, the small pores through which the cerebro-spinal fluid flows out of the fourth ventricle get blocked and the fluid gets dammed back inside the cavities of the brain. This produces *hydrocephalus*, or "water on the brain." By accurately directing a needle through the muscles of the back and between two vertebræ, the meninges can be pricked in the middle of the back, and cerebro-spinal fluid obtained. This is an important test, by which doctors can discover whether any disease is going on in the brain or meninges, for the cerebro-spinal fluid soon shows changes if any disease is present.

The delicate brain and spinal cord need careful wrappings if they are to be protected from the dangers of everyday life, and Nature once again has solved the problem by a soft fluid lining to the bony case, which, for its ingenuity demands all our admiration.

CHAPTER IX

THE SPECIAL SENSES—SIGHT, HEARING AND SMELL

WHAT do we mean by a "special sense"? In describing the sensations of touch, pain and others, we have been concerned with stimuli which affect the surface of the body directly, or arise from within. But as time went on senses developed which explored increasing space around the body. The first of these perhaps was smell. By it, an animal could tell at a distance, that an enemy was approaching. This warning gave time for action—whereas if the first approach of the enemy was shown by the sensation of his fangs in the victim's flesh, there was none.

So the animal developed senses for the conquest of space around him. Smell, hearing, sight—these are all such "special" senses. The sense of balance and position in space, though perhaps not strictly belonging to this group, is so closely connected with it both in structure and function, that we shall describe it here.

WHAT IS LIGHT?

First, our sense of sight. We have already, in Chapter IV, briefly described what is meant by wave motion, and how wave-length determines to some extent what effect energy may have when it comes into contact with the body. Light is an electro-magnetic form of energy, which travels in the form of waves through the ether, at a rate of approximately one hundred and eighty-six thousand miles per second. The wave-lengths of energy which are seen as light by the human eye, are from about eight thousand to four thousand Ångström units. Each of these units represents one ten-millionth of a millimetre. Rays of longer length form heat—shorter rays are known as ultra-violet. Rays still shorter than the ultra-violet, are X-rays.

Thus between eight thousand and four thousand Ångström units lie all the colours of the spectrum, about which there are one or two points we should note. All the colours of the spectrum together produce white light. There is no separate white colour—the spectrum itself consisting of red, orange, yellow, green, blue, indigo and violet. But white light can also be produced by mixing certain pairs of colours in correct proportions, such as yellow and violet. Sometimes if two are mixed, such as red and yellow, the intermediate one, orange, is formed.

Now any one who has used a camera knows that light rays can produce chemical change. The rays are absorbed into the substance (in the case of photography, a film or plate covered with a chemical

sensitive to light), upon which they act. These chemical changes may be reversed in many cases. The response of the delicate endings of the optic nerve to these chemical changes is the essence of vision.

But several other mechanisms are necessary before the power to see far and near is developed. These consist of the eyeball, and the muscles that move it, as well as the transparent *cornea* (pron.: kor-nee'-a) and *lens*.

Let us first describe the structure of the eye. From Fig. 1 you see that the eyeball is not quite round. In front the transparent cornea forms a slight bulge on the bigger circle of the main part of the eyeball. There are three main coats to this globe. The outer is the white *sclera* (pron.: sklee'r-a) which is continuous with the transparent cornea, and with it forms a layer enclosing the whole eyeball, except at the back, where the optic nerve pierces it. Inside the sclera is the *choroid coat*, which contains much pigment and many small blood vessels. As it sweeps round to the front, this coat changes

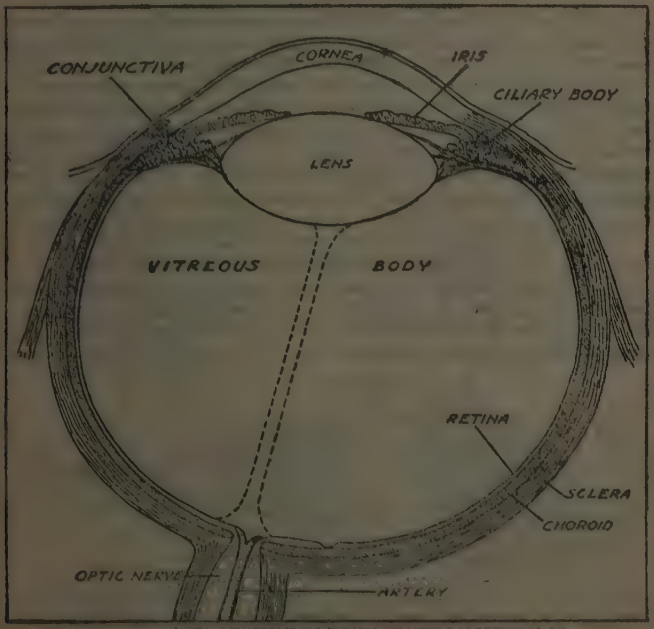


Fig. 1. *Section showing details of structure of the eye.*

slightly to form the *iris*, *ciliary* (pron.: si'lly-ary) *muscles* and glands. The third, innermost, coat of the eye is the *retina*, formed by several layers of very specialized nerve cells. Within the cavity of the eyeball there is a jelly-like clear material forming the *vitreous* body, which occupies the back part. In front of this is the lens, hanging just behind the curtain of the iris. The area between the lens and the cornea is filled by a watery material known as *aqueous humour*.

The iris which forms a continuation of the choroid coat, is that part which we look at for the "colour of the eye." Hanging in front of the lens it forms an incomplete curtain with a central space —the *pupil*. By contracting and relaxing, the iris alters the size of the pupil.

The lens is convex on both sides. It is enclosed in a very thin elastic membrane which controls the degree to which the surfaces may bulge. This degree of convexity varies with the focus.

HOW LIGHT IS BENT

It will now be apparent that the eye works on the same principle as a camera in its manipulation of light rays, so that an image is produced on the *retina*. The essential manipulation is *refraction*. Most people have put a straight stick into clear water, and wondered why it suddenly appears to be bent. This is not because the stick has suddenly changed its shape, but because the light rays in passing through the water and air, to our eyes have become bent. This bending of light rays is known as refraction. When light passes from one medium, such as air, into another such as water, or the clear tissue of cornea and lens, it becomes refracted in this way (Fig. 2).

How much the light ray bends, depends on the media in which it travels, and on the angle at which the ray meets the surface. A simple example of how refraction works would be to imagine a long line of men running on springy turf, obliquely towards a cornfield—not straight at it. Those at one end say the right, get there first

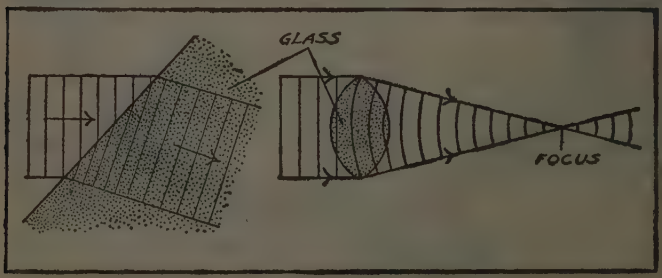


Fig. 2. How a lens bends or refracts light passing through it.

and are slowed down, whilst those on the left still being on the turf continue at the same speed, so that the line swings round as a whole. By the time all of them have entered the cornfield the line has swung round into a slightly different direction, in this case a fraction of a turn to the right. This is exactly what happens when light rays (not men) pass from an airy medium (the turf), into a denser one like water (the cornfield).

HOW THE EYE FOCUSES LIGHT

In the case of the eye therefore, the greatest amount of refraction of light rays will occur at the place where they leave the air to enter the dense medium of the eye. This is at the cornea. From the cornea the refracted rays now have to pass through aqueous humour, lens, and behind that, vitreous humour. But since these structures are more nearly similar in their densities, it is not refracted again so much, except perhaps at the lens.

We all know that the object of a lens is to focus light rays. Many of us have played with a lens on a hot summer's day, focusing the rays of the sun into a bright spot on a piece of paper, and since the heat rays as well as light are so focused, setting the paper alight. Now a convex lens achieves this result by a particular mode of refraction. Rays entering it as parallel lines (*see* Fig. 2), are bent by the rounded lens surfaces in such a way that they emerge converging towards one another. The point at which all these rays meet is called the focal point of the lens. In the eye the lens is so arranged that this focus lies exactly on the retina. So that the light rays end their journey at this spot.

SEEING NEAR AND DISTANT OBJECTS

But so far the lens apparatus has only dealt with parallel rays—which come from a distance. What about objects that are close to? When a nearby object is looked at, the light rays from it are separating as they go, are divergent. To focus these on the retina will require a different lens from that necessary to focus parallel rays.

There are two ways open to nature overcoming this difficulty. The problem may be solved either by moving the lens forward, away from the retina (which is the method used in a camera), or by increasing the convexity of the lens. The latter is the method adopted by the eye. Let us look a little deeper into its mechanism.

We described the choroid coat as changing in the front of the eye into ciliary body, ciliary muscle and iris. The lens is suspended from the ciliary bodies by thin suspensory ligaments, which enclose it in a kind of capsule back and front. The ciliary muscle is so arranged that, when it contracts, the ciliary processes are all pulled forwards and inwards—that is, closer together all round. The result of this is that the suspensory ligaments of the lens relax. This

permits the elastic lens to bulge, more particularly on its front surface, so increasing its convexity, and focusing the light from the near object accurately on the retina.

This ability of the eye to focus far and near objects is called *accommodation*. To demonstrate it to yourself, look through a window into the distance, then make an effort and bring your attention to a spot on the window-pane. This is an exercise for the muscles of accommodation—the ciliary muscles.

HOW WE BECOME LONG-SIGHTED

It can now be well understood how accommodation depends on an elastic lens and suspensory ligaments as well as active ciliary muscles. In old people we saw how the elastic tissue beneath the skin tends to lose its elasticity, contract and become fibrous tissue, so creating wrinkles. The same process happens in the suspensory ligaments of the eye, so that the lens cannot bulge forward as much as in earlier years, and near objects therefore cannot be so well seen. So it is that we see elderly people holding books at arm's length, in order to see the print clearly. They have lost the power of accommodation (become "long-sighted"), and need glasses with convex lenses to make up for what their own eye lenses are too stiff to do. Paralysis of the ciliary muscle will have the same result, because there will be nothing to pull the ciliary processes together and so relax the suspensory ligaments.

WHAT THE PUPIL DOES

The pupil of the eye plays a very important part, just as does the diaphragm in a camera, in cutting out excessive light which would blur the image on the retina or film of the eye. The pupil's size can be altered as necessary. The iris which surrounds the pupil is provided with two sets of muscles, one which runs circularly around the inner edge, and another which radiates from the centre like the spokes of a wheel. When the circular muscle contracts, the pupil becomes smaller, the opposite occurring when the radiating one comes into action.

If you watch somebody's pupils as he is doing the accommodation exercise, you will notice that as he focuses on the near spot on the window-pane, the pupils contract. This is because with divergent light rays, more pruning is necessary to get a clear image. The same contraction of the pupils occurs, and for the same reason, in a bright light. On the other hand, in darkness, the pupil dilates to collect all the light rays available. This is particularly well seen in cats, where the enormous dilatation of the pupil in the dark, sometimes allows the observer to see the green reflection from the back of the retina.

This nervous adjustment of size of pupil depends on the sympathetic

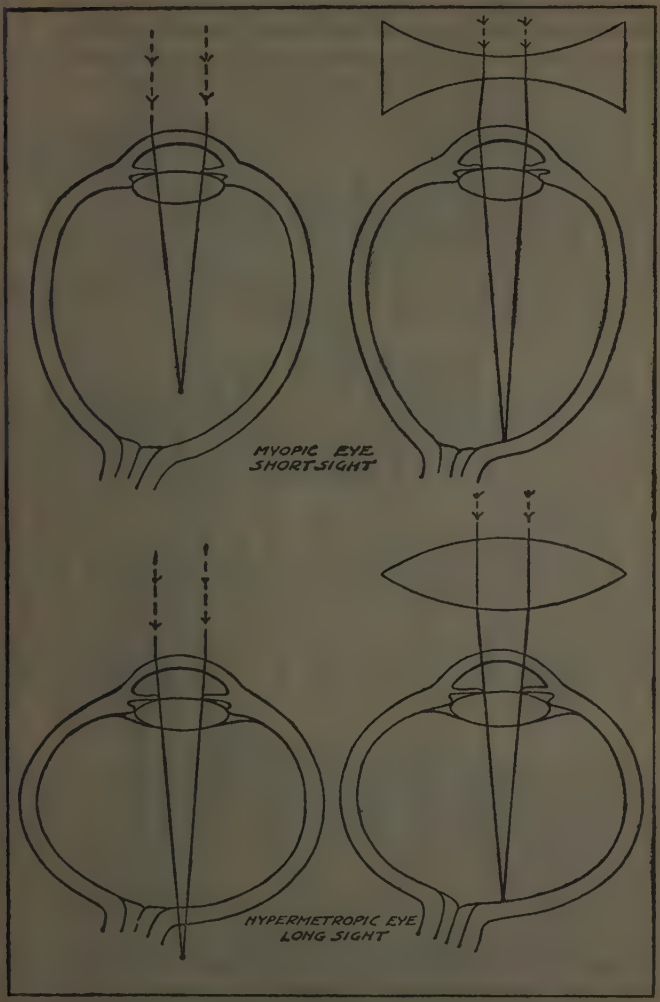


Fig. 3. *How common errors of vision are corrected by glasses.*

and parasympathetic nervous systems. The former supplies the dilator, radial fibres, the latter the circular, constricting muscle. As usual the one is balanced against the other in controlling the size of the pupil. Through these nerves the pupil may be contracted in a variety of conditions, for example in sleep or in poisoning by various drugs, which stimulate the parasympathetic, particularly opium.

Dilatation on the other hand, occurs in moments of emergency or great fear, as well as in poisoning by drugs, such as cocaine. Belladonna is a drug actually named " beautiful lady " on account of its action, when dropped into the eye, of dilating the pupil widely—a feature apparently thought to be of great beauty by medieval Italian ladies—and presumably gentlemen also. In anæsthesia, the size of the pupils is one of the most important guides as to the condition of the patient. When lightly anæsthetized the pupil is constricted dilating as anæsthesia becomes deeper.

THE PURPOSE OF GLASSES

A large number of people nowadays wear glasses. These correct errors of refraction which are due to faults in the refracting apparatus we have described. We have already seen how in old age the loss of elasticity of lens and suspensory ligament results in a stiffness of accommodation, so that the lens can see clearly neither very close nor far away—though usually the lens " sets " in the position of rest, which is in favour of long sight. True " long-sightedness " is due to the eyeball being too short, so that the focus of rays produced by the lens falls behind the retina. This will obviously be helped by convex lenses, increasing the focusing power of the lens. Short-sightedness is due to the opposite set of circumstances. Here the eyeball is too long, and the focused image falls in front of the retina. Here concave lens, which counteract some of the converging action of the natural lens, will restore the focus on to the retina. The principle is made clear by reference to Fig. 3.

WHAT IS ASTIGMATISM?

Astigmatism is a more complex error, in which the different parts of the lens or cornea are distorted out of their true shape—and the slightest distortion sends the light rays out of their course (so that, for example one cannot see the two hands of a clock at the same time). Tests are done therefore to measure exactly what distortion is taking place, and glasses can be made to correct it. Every one has this error to some extent; only in some people it is sufficient to produce real deficiency in vision.

In some cases persistent action of the ciliary muscle by exercising accommodation may overcome the slight defect as far as vision is concerned, but at the expense of symptoms of eye-strain. Headache, is particularly common as a result of strain on the ciliary muscle.

The actual sensory organ of the eye is the retina. Here it is that chemical changes occur as a result of the action of light, to which

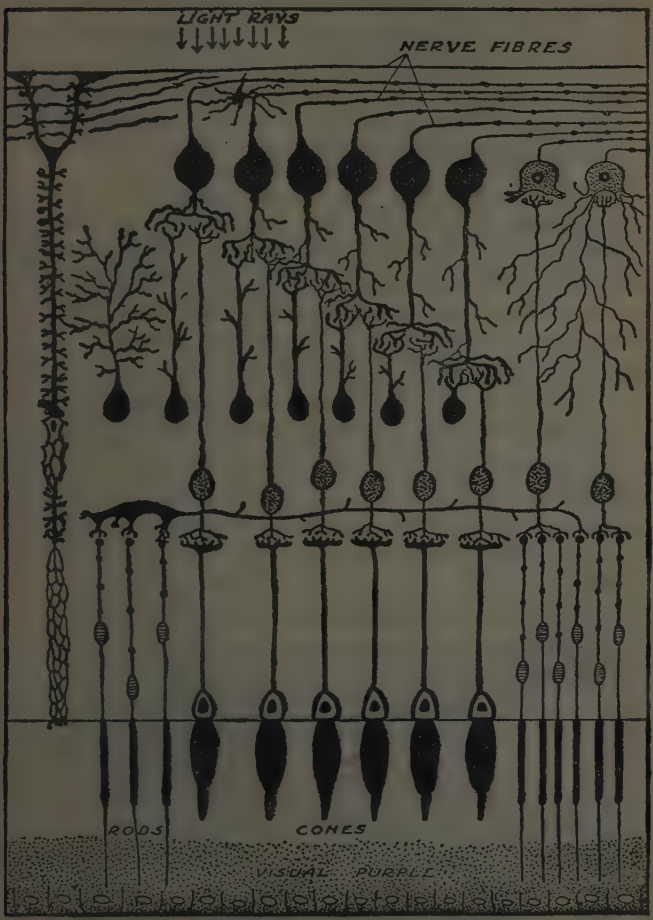


Fig. 4. A cross section (enormously enlarged) through the retina of the eye, showing the delicate rods and cones.

special nerve endings are sensitive, so that nerve impulses are produced which travel to the brain, via the optic nerve. Under the microscope the retina (Fig. 4) is seen to be formed of many layers of cells. The two main layers are an outer pigmented and an inner nervous one. It is the nervous layer which is subdivided into further complex layers of cells. But this is really to be expected if one remembers that the optic nerve is really a specialized outgrowth of the brain, and therefore in the retina there have got to be crammed the three sensory neurones, which we have always found to exist between the receptor organ and the brain.

THE LIGHT RECEPTOR CELLS

The outermost layer of these cells, that is those next to the pigmented layer of the retina and choroid coat, is composed of curious cells, called *rods* and *cones*. These are the actual light receptor cells, and they connect with other nerve cells before, finally, the innermost layer is produced, this consisting of nerve fibres. All these nerve fibres converge towards the optic disc, which is situated at a point slightly to the inner side of the middle of the retina. Here the nerve fibres form the optic nerve (Fig. 1) which turns sharply backwards, piercing all the coats of the eyeball to enter the orbit behind.

There are several remarkable points about this design of the retina. First, what an extraordinarily inefficient mechanism it is to have the light penetrate the medley of nerve cells and fibres, before reaching the sensitive rods and cones. It is a change to be criticizing Nature's handiwork instead of always praising it. But here there really does seem to be justification for criticism. Actually the reason for this peculiar arrangement lies in the development of the retina, which we cannot enter into here. But even this only describes how the mistake is made, not why. There seems to be no doubt that if the nerves to the retina entered from behind, a man's vision would be much sharper—keener than a hawk's perhaps—and surely this would be an advantage.

HOW WE SEE

But a partial solution to this apparent error is provided by the neat device of placing the optic disc just inside the centre point of the eye, on which the main axis of light falls. Instead, a very sensitive spot, the *fovea centralis* occupies this position. Here the nerve fibres and cells in front of the cones have been entirely swept on one side, so that over this small area, rays of light do impinge straight on to the cones. In the fovea there are masses of cones, and no rods. This fact enables us to grasp the different functions of the two. Cones have the property of accurate vision, of perceiving fine detail in shape or colour. They are therefore situated on the central light axis of the eye. When you consciously look at anything you use the cones: but these structures are bad at picking up faint glimmers of light

of very low intensity. This is the function of the rods, which are found in abundance all round the periphery of the retina. These are responsible for "seeing something out of the corner of the eye," particularly some movement or a glint of light. When this occurs, the eye is turned so that the cones bring their accuracy to bear on the object just glimpsed.

The third peculiarity about the retina is the "blind spot." Where the fibres of the optic nerve form the disc there are no sensitive nervous elements, so that light falling on this spot will produce no impulses to the brain, and therefore no image. Close your left eye and look at the cross in Fig. 5. Now move the book slowly from side to side in front of you. In one position the white circle will suddenly disappear. Light from it is flowing on to your blind spot. Usually we are unaware of the existence of this because we see with both eyes, and no object can be so situated that we are looking at it with both blind spots at once.

THE BASIS OF THE RETINA

Let us now briefly follow what happens when light falls on the retina. We mentioned that the rods and cones rested on the pigmented layer of the retina. This pigment is known as *visual purple* (Fig. 4). It is present at the bases of the rods, not the cones. When light falls on the retina, visual purple comes down between the rods, which shorten to about a quarter of their original length. The light is absorbed by the visual purple, which is itself destroyed and so bleached in the process. This change in the pigment stimulates the rods, which send off impulses along the optic nerve fibres to the brain. As soon as the light stimulus stops, so does the change in visual purple, so that the rods cease discharging impulses. Visual purple pigment is chemically, closely related to Vitamin A, and tests

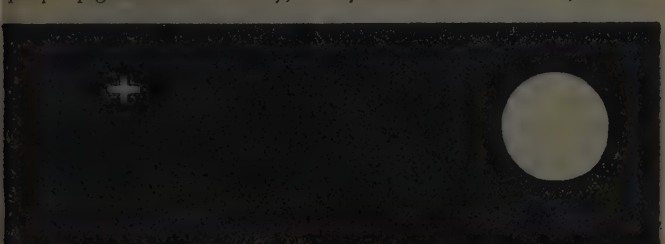


Fig. 5. The blind spot of the eye. Hold the book seven to nine inches from the face, shut one eye and look fixedly at the white cross. As the book is moved slowly from side to side the white spot will disappear and reappear.

have even been devised for sensitivity to faint light in darkness, as an indication of vitamin A deficiency. Another interesting point about the pigment is that lack of it is responsible for "night blindness." There are some people who cannot pick up the faint lights and shadows of night time. This is very necessary for such a person as a sentry on guard in war time. No doubt many a poor man was punished in the War for neglect of duty of this kind.

MUSCLES OF THE EYE

It is obviously desirable that our eyes should be able to scan as large an area around us as possible. For this purpose, each eyeball is provided with six small straps of muscles to move it in all directions (Fig. 6). We saw above that these muscles were supplied by cranial nerves from the mid-brain. These nerves are so arranged that the movements of each eye work together smoothly. For instance, on looking to the left, the outside muscle of the left eye, must work in harmony with the inside muscle of the right eye, so that the eyeballs shall swing round together. Complications of eye movement in man have arisen from the fact that his eyes have come round to the front of the head, from the side, where they are in a horse. This confers the great advantage of stereoscopic vision—or vision in depth, so that we can tell which of two objects in the distance is farther away. This is very poorly achieved with one eye only, or with one camera plate which acts like one eye. For this reason cinema films do not convey

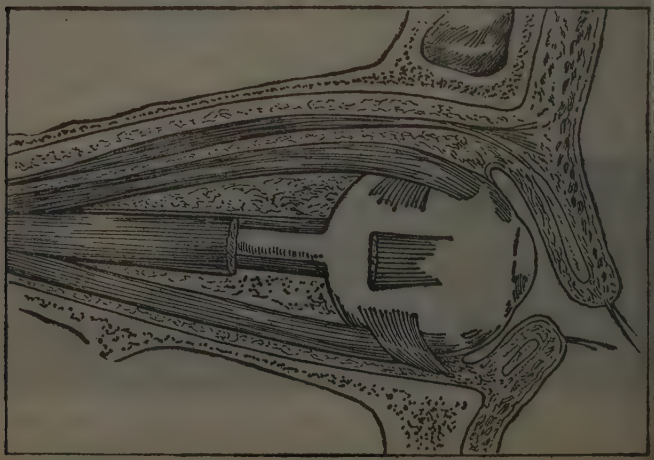


Fig. 6. The muscles of the eye.

the full illusion of depth. Recently a stereoscopic film has, however, been shown, and shots taken of such subjects as an approaching express assume a terrifying realism.

When an object which is very close to the face, is looked at, then the two eyes converge so as to focus on it. This is another feature of accommodation, and is again due to the subtle interplay of the muscles of each eyeball.

WHY WE SOMETIMES SEE DOUBLE

If an image is seen on the right the light rays from it fall on the nasal or inner side of the right eye, and on the temporal or outer side of the left. This does not, however, produce two images, because experience has taught that such impressions should be interpreted as one. But if any other spot on the retina is affected then double vision results. If one of the muscles moving the eye becomes paralysed for instance, so that both eyeballs do not move together, this double vision occurs. A squint is where the eyeballs are permanently out of line with each other.

Colour vision is a very complex subject, and not much is to be gained by outlining the various theories put forward to account for it. The point upon which most of these agree, however, is that different colours give rise to different chemical reactions in the retina. Be this as it may, there are a remarkable number of colour-blind people in the world—almost one man in ten is colour blind, but only one woman in fifty.

The eye's armour consists of the eyelids and tears. These, with the *conjunctiva* (pron.: con-junk-ti'-va), or *mucous membrane* of the eye, protect it from all the dangers to which it is exposed (Fig. 7).

THE EYE'S ARMOUR

The eyelids are composed of two sheets of fibrous tissue. The upper one is far more movable than the lower, and has a special muscle attached, to raise it. If you pull on the eyelid so as to turn the edge outwards, you will see that behind the eyelashes there is a row of little holes. These are the openings of small lubricating *tarsal* glands. At the inner end of each lid is a large hole—the tear duct, for carrying away moisture from the eye.

The conjunctiva is the lining mucous membrane which passes up and down behind each eyelid, and over the front of the eyeball, where it becomes quite transparent. At its inner border it may form the " third eyelid." When it is inflamed " conjunctivitis " or " pink-eye " is the result.

Above and to the outer side of the eyeball is the tear, or *lachrymal* gland of the eye—from which small ducts lead the tears into the front of the eyeball. Here they flow down until they are worked into the tear ducts, which eventually open into the nose.

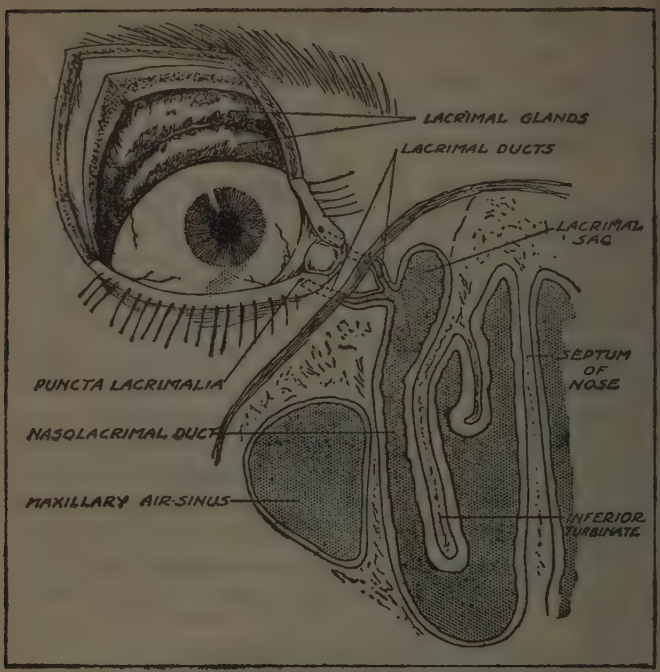


Fig. 7. Tears. Why your nose "runs" when you cry.

Normally the amount of fluid secreted by the lachrymal or tear gland, is just sufficient to keep the eye well lubricated, but under the stress of emotion or pain, this gland secretes more than can be taken away by the lachrymal ducts, with the result that the fluid flows over on to the cheeks as tears. The curious connection of tear ducts to the nose accounts for the way one may "sniff away one's tears."

Crying is a peculiar response to unpleasant events. Presumably it at one time cleared the vision of the animal and was of some use. But it is difficult to see what use it can be to man. Newly-born infants cannot shed tears. They may scream and yell, but true tears do not flow until some months have passed.

* * * * *

The next great special sense is that of hearing. Just as the eye is a special apparatus, designed to detect vibrations in the ether, which

are interpreted as light rays, so the ear is designed to detect another type of vibrations representing sound.

Light and sound both travel in waves through space. But apart from this similarity they have little in common. Light waves we likened to the ripples on a pond, and if you put a cork on that pond the ripples would move it up and down, but not along the surface. So that light waves are said to be transverse—or across the direction of travel. Not so sound waves. A model of a sound wave is presented by an engine shunting trucks. If you watch this, you will notice how the shunted truck as it joins the stationary line pushes its neighbour on to the buffers of the next, and so on. This clash of buffers goes all the way down the line to the end, in a wave. If the trucks were particles of atmosphere the engine represents something "making a noise."

WHAT IS SOUND?

Again, we can see stars flickering millions of light years away—that is to say it takes light travelling at the rate of some one hundred and eighty-six thousand miles per second, millions of years to reach us. This fact indicates that light must travel by some other medium than our earthly atmosphere, which extends only a few miles into space. This medium has been called the ether. Sound, however, travels in the atmosphere—so that we cannot hear anything where there is no earthly atmosphere, and the "music of the spheres" is nothing but a beautiful fantasy.

Thirdly, sound waves are much larger than light waves, and travel much more slowly. It is for this reason one sees the flash of lightning before hearing the thunderclap, and the closer the two are together the more likely is one to be struck. The same reasoning holds for watching a gun being fired. If the gun is in the distance, the flash is seen long before the sound is heard.

QUALITIES OF SOUND

Sounds have various qualities, which we mentioned in describing the mechanism of the voice. Pitch is related to the frequency of vibration of waves—the higher the frequency the higher the pitch or note. For instance, middle A on the piano which is used as a standard note to which instruments are tuned, has four hundred and forty vibrations per second. The octave higher eight hundred and eighty, the octave lower two hundred and twenty, so that an octave doubles the frequency of vibrations. Loudness we saw to depend on the size or amplitude of the sound wave.

Now, as with the eye, special end organs or receptors, must be developed if these waves in the atmosphere are to be detected. The ordinary skin sense organs cannot do it. Let us see how the ear performs this task.

The human ear (Fig. 8), consists of three main parts, the external

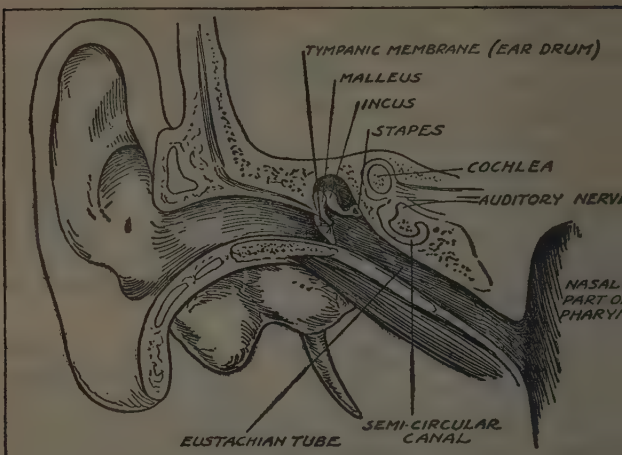


Fig. 8. The chief parts of the ear.

ear or *pinna*, with a passage, the *external auditory meatus* (pron.: mee'
tus) leading to the middle ear. This consists of a series of levers desig
to magnify and transmit the impulses from the ear-drum at the
of the external auditory meatus, to the inner ear which lies dee
embedded in the temporal bone of the skull.

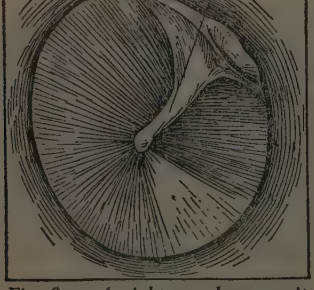


Fig. 9. A right ear-drum as it would appear from the outside.

The external ear in so
animals acts as an ear-trumpet,
collecting sound waves and p
ing them on. It may also, by
muscles be " pricked " or switc
in any direction, so locating
sound—a capacity of vital imp
tance for any wild animal.
in man there is no evidence t
the pinna does either of th
tasks. The shell-like curves of
human ear command admirat
for their beauty, but are useles
detecting sound waves, for if
these spaces are filled with w
or if the pinna is cut off complet
there is no loss of hearing, as
as can be detected.

The external auditory meatus leads from pinna to the *membrana mpani*, or ear-drum. The reason for the existence of this tube is mply for conduction of sound waves, and protection of the drum. he meatus runs forwards and inwards, so that the delicate drum is ot easily seen from outside, and is protected from draughts and injury. long the inner surface of the tube are the *sebaceous* glands, whose ecial secretion is not the ordinary hair nourishment, but wax. his bitter, unpleasant substance is a great deterrent to any chance nsects, such as earwigs, which may consider the ear a shady retreat.

Waves of sound having passed through the pinna and down the eatus now impinge on the drum, and are taken into the middle ear -a truly remarkable device. The membrana tympani is a membrane hich, as its name describes, plays the part of a drum (Fig. 9). The ound waves are the drum-sticks which set it into vibration. Attached the drum on its inner side, are three small bones, the *malleus*, *cus* (pron.: ink-us), and *stapes*, whose names in English mean the ammer, the anvil, and stirrup (Fig. 10). By its handle, the hammer attached to the vibrating ear-drum, so that its head beats on the nvil. This little bone has a strangely-shaped process joining it to he stirrup-shaped bone, whose foot-piece fits into an oval hole in the mporal bone, in which lies the inner ear. With every vibration of he ear-drum therefore, these small bony levers transmit an mpulse to the oval window, hrough which it enters the inner ar becoming a nerve impulse.

Since sound is the result of ompression and rarefaction of the tmosphere, it is obviously vital hat apart from sound waves, the tmospheric pressures should be ept the same on both sides of the ar-drum. For suppose all the air n the middle ear were absorbed, hen the vacuum would pull on he ear-drum and suck it inwards, r "retract" it, so that it would ot be able to respond to the sound ibrations coming to it. Nature as achieved this equality by eans of the *Eustachian tube* pron.: ū-sta'ke-yan, *see* Fig. 8), hich runs from the middle ear to he roof of the pharynx behind the ose. Usually this tube is closed, ut by swallowing or yawning ne can usually open it. The slight

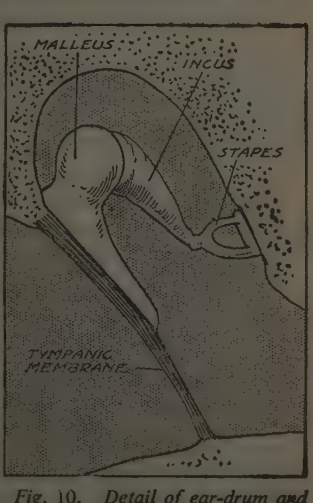


Fig. 10. *Detail of ear-drum and small bones of ear.*

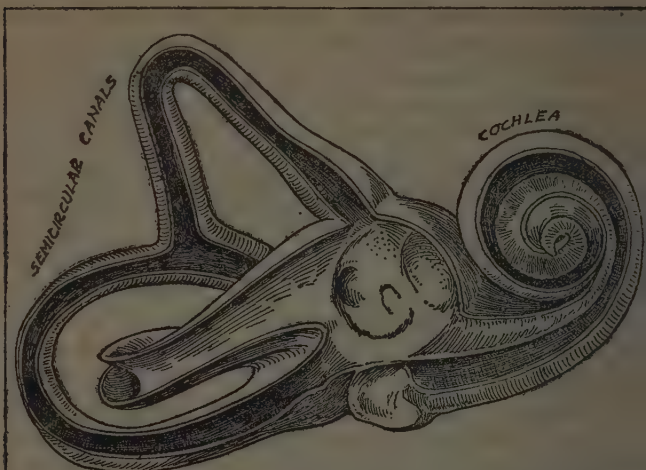


Fig. 11. *The labyrinth of bone in the inner ear in which the essentia hearing organ lies, with the semicircular canals.*

click that one sometimes hears, is due to this sudden opening. I there is inflammation of the cells of the tube, as with a heavy cold then it sometimes gets blocked and cannot open, so that the air i the middle ear is absorbed, the drum retracts, and deafness, whic we all know often accompanies colds, is the result.

THE INNER EAR

Deep in the temporal bone is the inner ear, consisting of a labyrint of tubes cut out of the bone, and filled with fluid, in which is immerse the sensitive organ (Fig. 11).

The first thing we notice on examining this bony labyrinth, is th astonishing fact that half of it has nothing whatsoever to do wit hearing. While one part, the *cochlea* (pron.: ko′k-ly-a) is the essentia organ of hearing, the other, the *vestibule*, and *semicircular canals* ar an essential part of the apparatus of balance and posture. Wh these two quite different functions should be developed with this clos anatomical relationship is very difficult to answer, unless it is that i the process of evolution these two faculties were found to b advantageous simultaneously. We will describe the vestibule an semicircular canals later, meanwhile let us try and understand th mysteries of the cochlea.

The cochlea consists of a spiral tube wound two and a half time

round a central column of bone, inside which runs the auditory nerve. Projecting into this tube all the way along, is a corresponding spiral bony ledge, which divides the hollow of the tube into upper and lower parts. The upper part is divided by a thin membrane into two compartments, making three spaces in all (Fig. 12). The continuation of the bony shelf forms the *basilar membrane* (Fig. 13). On this is the spiral *organ of Corti*, consisting of tall cells with processes like hairs protruding from their tops. From their bases run nerve fibrils, across the bony spiral shelf to the central column of bone, where they join other similar nerve fibres to form the auditory nerve. To the upper edge of the bony spiral is attached the *membrana tectoria* —or roof membrane, which as you see overhangs the delicate hair cells.

DETECTING SOUND WAVES

Now let us follow a sound wave which has moved the footpiece of the stirrup bone in the oval window. Through this window the vibrations enter the uppermost space or *scala vestibuli*, along which they travel up the two and a half twists right to the top of the spiral. As they travel they press on the thin vestibular membrane which separates the upper from the middle space. The pressure is thus transmitted to the basilar membrane which moves downwards, in doing which, however, it raises the pressure in the lowest space, or *scala tympani*. This pressure is communicated down the spiral curves until it reaches a membrane opening on to the middle ear, the round

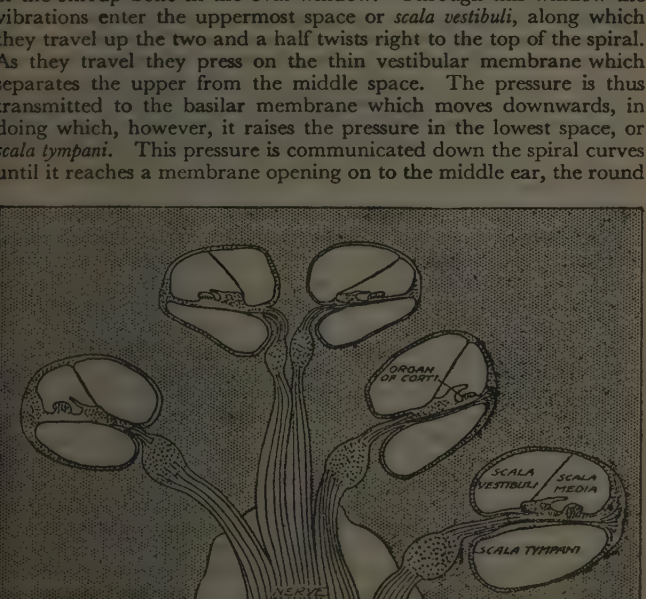


Fig. 12. Transverse section through cochlea (or apparatus for hearing), showing the organ of Corti where the impulses are formed which travel up the nerve of hearing to the brain.

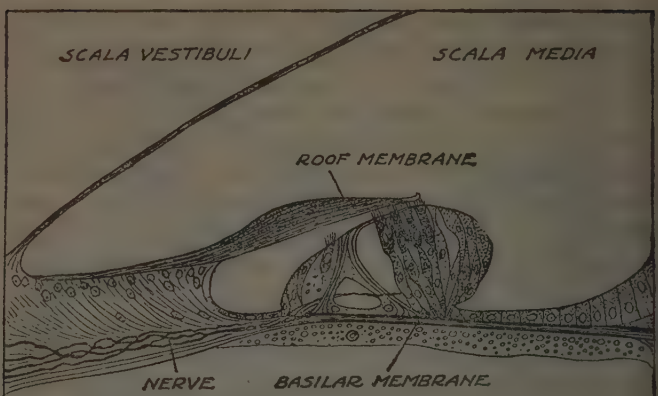


Fig. 13. *Organ of Corti* (*much magnified*), *showing the sensitive hair cells.*

window. This now in its turn vibrates. The basilar membrane with its sensitive hair cells thus vibrates to and fro as the pressures on each side of it vary, so causing the hair cells to come into contact with the roof membrane, which sends up nerve impulses along the auditory nerve.

WHAT IS PITCH?

Now the basilar membrane is not the same width all the way along the two and a half spirals, being narrower at the base than it is at the apex. By this means, pitch of sound is appreciated. If you put down the loud pedal of a piano, and sing a note strongly you will hear the piano continuing with that note after you have stopped. Suppose you have sung the note A at a vibration rate or frequency of two hundred and twenty per second, the corresponding wire inside the piano is tuned to vibrate at this frequency, and so is acted upon by the sound waves from your voice and made to vibrate. The wires on each side having different frequencies are not affected in this way. This phenomenon is known as "resonance." It applies to the ear. The fibres of the basilar membrane vary in their length, just as the wires of a piano do. So that with sound of a certain pitch, particular basilar fibres vibrate—those that are "tuned" to the same frequency, that is, are in resonance. The others stop still. This vibration stimulates the particular nerve endings, so that impulses pass along the nerve fibres of a similar frequency, e.g., two hundred and twenty per second. This series of impulses finally reaches the brain, where a mystery is performed and it is transformed into our consciousness as the note A.

In humans the range of audible pitch is from about thirty to fifteen thousand per second. Actually, the lowest tone from the largest organ pipes is sixteen vibrations per second. This note is hardly musical. Sounds in this region are just throbbing noises with no definite pitch to them. At the other end of the scale, the human ear fails to register pitch above a frequency of fifteen thousand. The top note of a piano is four thousand two hundred and twenty-four vibrations. This range then, of from thirty to four thousand seems to be that in which we find pleasurable stimulation of the spiral organ of Corti. Animals can hear higher pitches than man. Dogs, for example, can be called by blowing a whistle whose pitch is too high for a man to hear.

REAL NATURE OF DEAFNESS

Deafness it will now be understood, can be caused by anything interfering with the passage of the sound vibrations on the one hand—such as wax in the external auditory meatus, or disease of the small bones of the middle ear. Also, anything affecting the nerves which conduct the impulses will affect hearing. In the first form a tuning-fork which cannot be heard when held outside the ear, can be heard when placed on the bone of the skull, since the vibrations of the fork are carried through the bone to the healthy inner ear. This principle lies behind many of the " aids " to deaf people.

THE OTHER PART OF THE INNER EAR

We must now turn to that other part of the labyrinth locked away in the temporal bone. The anterior part has gone to make the cochlea or auditory apparatus, the posterior part (*see* top of Fig. 14), is divided into a *saccule* (pron.: sa′k-yoo-lee) and *utricle*, and three semicircular canals. In these cavities there are special sense organs, consisting of hairs which are plentifully supplied with nerves. Those in saccule and utricle are provided with little masses of chalk which, being attached to the hairs, pull or lie on them, depending upon the position of the head in space. These organs are, therefore, always sending up messages to the brain concerning the position of the head in space, for each position of the head causes a different combination of pulls on the hairs in these so-called *otolith* organs.

This type of mechanism for keeping balance is very primitive and is present in such animals as lobsters and crayfish. In the latter, if the chalk is removed and replaced by iron, all remains perfectly normal. But if the iron is attracted by a magnet, then the crayfish gets quite a wrong impression of where it is and straightway loses his equilibrium.

Behind the utricle, and opening into it are the three semicircular canals, on each side. These are arranged in three planes, that is they form three sides of a box. The outer canals lie horizontally, the

other two vertically at right angles to each other. At the end of each canal, as it opens into the utricle, is a dilatation called the *ampulla*, inside which is another special sense organ, composed of hair cells, just like those in utricle, except that there are no chalk particles

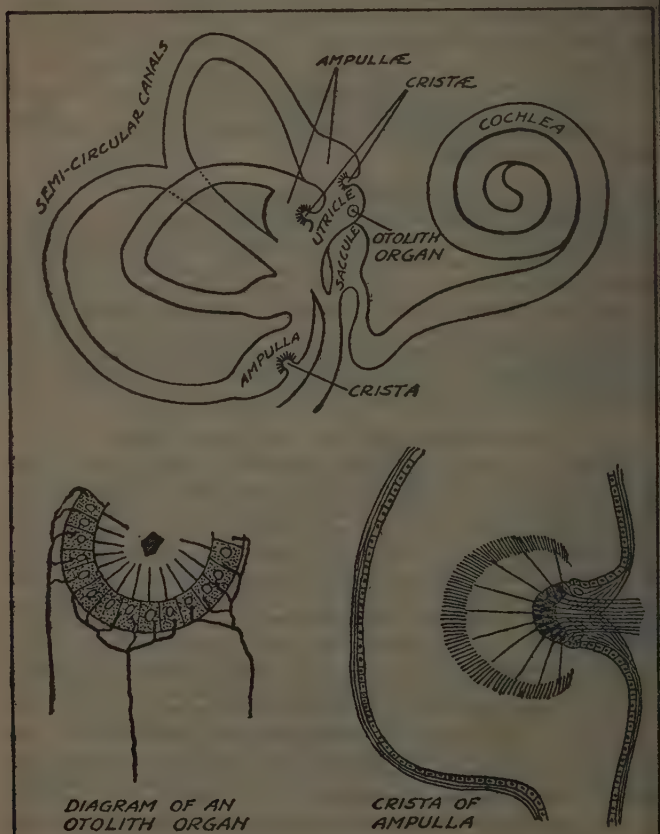


Fig. 14. (Top) *The semicircular canals, the organs which tell you the position of your head in space. The nervous impulses are sent up from the otolith organ* (bottom left) *and from the crista of ampulla* (bottom right)

ocked in them. These hairs are sensitive to the movement of fluid ver them. All the tubes are filled with fluid, and as the head noves, turning from one position to another, the fluid inside the emicircular canals is jerked from one position to another. For xample, if the head is turned from side to side, the fluid in the orizontal semicircular canals—both outer ones in this case—timulates the sense organs in the ampullæ, conveying to the brain nformation of what has happened.

While the otolith organ conveys to the brain information of where he head is in space at any particular moment, the semicircular anals convey knowledge of its movement, so that these two parts upplement each other in their action.

A CAUSE OF GIDDINESS

If these sense organs are irritated as in some forms of disease, then iddiness is the result. This also happens if you turn round and ound many times and then stop suddenly. The fluid in the semi-ircular canals lags, and is not restored to equilibrium at once, so it till stimulates the sensory hairs in the ampulla, informing the brain hat you are still twisting round, whereas you are not. Impressions rom your semicircular canals do not agree with those from your yes and feet—a sense of confusion as regards your true position arises, nd you are giddy and stagger, until the fluid comes to rest.

On board ship again constant movement of the semicircular anals is said to be responsible for the impulses which create sea-ickness. It is a curious thing how abnormal impulses from the emicircular canals are closely associated with nausea and sickness. f you make yourself giddy there is a curious sickly feeling with it. Disease of the semicircular canals which is marked by uncontrollable iddiness in which the patient often falls down flat in the street, is lso commonly accompanied by violent vomiting.

KEEPING OUR BALANCE

But you may say there are many other methods of maintaining osture and equilibrium. This is true, and it is perhaps interesting o see how they all work together. The three great mechanisms oncerned in balance are: (1) Vision. We all know how much asier it is to balance delicately with our eyes open than with them hut. This is partly through nervous impulses from the retina giving ccurate information, and partly through afferent impulses along the nuscles which control the position of the eyeball. In lower animals uch as dogs, the eyes are perhaps even more important than in man. (2) The labyrinth—semicircular canals and otolith organ. We have een how these are concerned with the position and movement of he head in space. But with the head must be co-ordinated the est of the body. This involves: (3) *kinæsthetic* (pron.: ki′-nees-thet-ik)

sensations. This formidable word simply means awareness o movement. If the head turns to one side, it possesses eyes anc semicircular canals for complete information as to its whereabouts. but the rest of the body must be informed and make the necessary adaptations of posture. So that that part of the body which joins the head to the trunk (the neck), conveys the information to the brain of the relative positions of the two parts, head and trunk. Nerve fibres run to the cerebrum and cerebellum conveying this message, whence impulses pass to the limbs and body so that they move as required. The whole mechanism is only one of making the body react as a whole to information supplied by a special small part. It is indeed a highly complex example of integration.

THE LINK BETWEEN TASTE AND SMELL

The last of the special senses we must describe are taste and smell We group them together because they have so much in common In one way smell is only taste projected into space. For whereas taste occurs by direct contact of a piece of food on the special taste-buds, the same piece of food usually is capable of making indirect contact with the sense of smell at a distance. It is as if taste threw out a long tentacle—the power of smell. Both these senses are sensitive to chemical stimuli. This forms a contrast to vision and hearing, where physical changes in the form of light or sound waves provide the stimulus. So that whereas vision and hearing are in man highly developed in comparison with lower animals, smell tells the opposite story. Fishes have enormous smell brains of great sensitivity, and the power of smell in dogs is well known. But man, now in the erect posture, and without the art of putting his nose to the ground, has lost his sense of smell to a large degree.

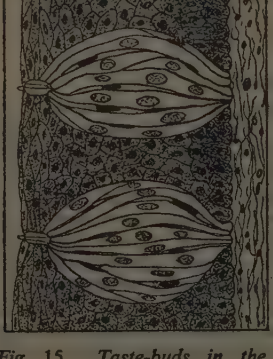


Fig. 15. *Taste-buds in the tongue.*

The sense of taste is served by numerous little packets of cells called *taste-buds* (Fig. 15), which are scattered over the tongue, particularly towards the back. Through the small mouth of the oval taste-bud projects a hair. This is the sensitive receptor end organ, and is stimulated by solutions which come into contact with it. From its base nerve fibres run to join one of two main nerves all ending their course in the pons and medulla.

It is curious how similar these receptor cells of taste are to the

receptor cells of hearing. Four main kinds of taste are recognized, sweet, bitter, sour and salt. Bitterness is curiously located at the back of the tongue—and is hardly present at all in the front. It is for this reason that the real unpleasantness of a quinine mixture is not appreciated until it is swallowed. Sweetness and sourness are more marked in the front and sides of the tongue. Some tastes can neutralize others. For instance, a dilute sugar solution may be made quite tasteless by the addition of a pinch of salt.

HOW DRUGS AFFECT TASTE

Drugs may affect one type of taste-bud and not another. For example, cocaine if applied to the tongue, acts first by diminishing pain and touch sense, then bitter, sweet and sour senses, leaving only the salt taste.

What actually produces these tastes has never been discovered. Acids produce sourness, probably as a result of the liberation of H ions in solution, which we saw to be the essential characteristic of any acid. But beyond this it does not appear possible to say what decides.

When it comes to the question of subtleties of flavour in a dish, which seem to mean so much to some people, there is no doubt that other senses besides that of pure taste are involved. Such humble taste-bulbs as we have just described are quite incapable of appreciating some "exquisite" French sauce, or the bouquet of a vintage wine. In this the sense of smell and also touch play their parts. Touch comes into it by virtue of being responsible for the "biting" quality that makes you smack your lips. Smell is perhaps even more important than taste to the epicure. We might even define the epicure as a man with an exaggeratedly developed sense of smell.

WHY A COLD AFFECTS OUR SENSE OF SMELL

How important smell is, is very beautifully demonstrated in one who has contracted a common cold. Here the mucous membrane of the nose is inflamed, the power of smell has gone, and so has the taste of food—very largely. With a bad cold it is impossible to distinguish between a morsel of onion or apple placed in the mouth—and yet you would have thought the difference pretty obvious. This is a little experiment worth trying. Or if you do not want to wait for your next cold, blindfold a friend and tell him to hold his nose tightly. Cut up an onion and an apple into small pieces and place one in his open mouth, asking him to say which it is. This makes quite an amusing parlour-game.

The organ of smell is a limited part of the nasal mucous membrane. In Fig. 16 you see a section through the nose. The *turbinate* bones are the radiators which heat air, as it passes back to the pharynx. Right at the top the mucous membrane contains large, tall cells.

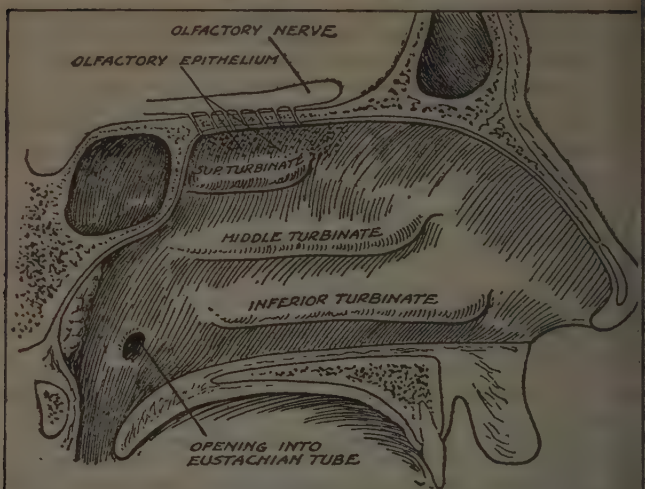


Fig. 16. *A section through the nose showing the turbinate bones and th area for smelling. Notice how small this is in man.*

Each cell is connected with a nerve fibre which runs into nerve cell from which fibres finally emerge, penetrating the bony roof of th nose to enter the skull, where they run into a swelling, the olfactor bulb. From here the fibres follow the olfactory tract, where w have already seen them on the under surface of the brain.

In ordinary breathing, air passes to and fro below the middl turbinate bone, and so does not strongly stimulate the olfactor nerves. " Sniffing " is a device for diverting the main stream of ai upwards to the sensitive smelling area. The *olfactory epitheliu* (pron. : ep-py-thee'-ly-um), moistened by mucous glands, dissolve particles, which thus stimulate the sensitive nerve endings.

WHAT IS SMELL?

What stimulates the sense of smell? This is a question that cannc be accurately answered. Minute quantities in the air are sufficien Less than one part of a substance in ten thousand millions is said t have been smelt by man. If a man can smell this, what can a do do? Substances with heavy molecules are said to give rise to smell so accounting by lack of diffusion for the way a smell " hangs about " an object.

And so we come to the end of our description of the special senses

In many ways the eye, ear and nose are the most marvellous of all Nature's handiworks in their delicacy and subtlety.

It is interesting to pause for a moment and realize, however, what a small portion of our environment is explored by our senses. We noticed how at both ends of the light spectrum—wave-lengths of longer or shorter types could not be detected by the human body. X-rays are an example of the short type for which we have no sensory organ developed. Wireless waves are longer ones to which we are equally insensitive, until they are converted by our radio sets into sound waves. Cosmic rays from the stars saturate our bodies, and yet we are entirely unaware of them. The world must contain many more waves and phenomena of all kinds, which we fail to perceive.

This very fact, that we know many rays to which we are insensitive, should make us pause before we ridicule people who claim to have a sensitivity which most of us have not got. Some people are said to have a "sense" of direction. Place them anywhere, and they will always know which way to go. Certainly some animals such as cats and dogs seem to have this "homing" sense. And the fascinating migrations of birds surely must be controlled by some special sense.

Perhaps this argument applies even to those who claim to see visions, or to the telepathic sense of the mystic or spiritualist. Who knows? It may well be that these fortunate (or unfortunate) people, "sense" things in a way we ordinary mortals cannot do.

CHAPTER X

FOOD AND ITS DIGESTION

Animal bodies are active. This activity expresses itself in the working of the muscles, or as heat. Both these expressions of energy are derived from the burning of fuel in the body, in the same way as petrol is burnt in an engine. This fuel is food. But in any engine we know of, small particles are worn off, bearings become loose, and have to be renewed. This renewal and repair is another function of the food of the body.

In children the engine is growing up, so that not only must worn parts be renewed but they must be increased in size—this again is achieved through food.

But as fuel is burnt, waste products are created and these have to be cleared out of the body since they are harmful. Thus we can measure how fast the body is building itself up by measuring the food taken in, and we can measure how fast it is burning by measuring the used products excreted. Normally these two processes are always accurately balanced.

Food then, supplies energy. How much energy is requir depends on how much activity there is. A labourer obviously requir much more energy than a clerk.

There are two great types of food—the inorganic and the organi The first class consists of water and salts, the latter of fats, protei or fleshy foods, and carbohydrates (bread, sugar, etc.).

The most important inorganic food is water. This substance is necessity to all forms of life, and deprived of it a man dies in a fe days. How much each person needs per day depends on how muc he excretes by kidneys and skin, but at least three pints is consider an average figure. One must remember here that many foods, suc as vegetables and fruits, contain a large amount of water.

WHY THE BODY NEEDS SALTS

Many salts are necessary to the body. Ordinary table-salt sodium chloride, but calcium phosphate is necessary in the buildi of bone, and the carbonates play a very important part in the bloc —all these and more, must be present in the food. In fact eve organ of the body depends upon salts for its efficient working, althoug these do not actually supply energy in the form of fuel. Water ar salts therefore, are just as essential to life as the other more obvio foods. This also applies to the vitamins, which we shall descril later.

The organic foods are all changed in the body, broken down in simpler products—a process which liberates energy in the body, in th same way as burning coal liberates energy in the form of heat.

WHAT IS A CALORIE?

The energy which can be derived from these foods is measur in what are known as *calories*. A calorie is the amount of he necessary to raise one gram of water from fifteen degrees Centigra to sixteen degrees. A large Calorie (always spelt with a capital C is the heat required to raise a kilogram (i.e. one thousand gram of water through the same temperature. A Calorie is thus o thousand times as large as a calorie.

Now if the various kinds of food are burnt in a special chambe where the amount of heat given out is measured (a calorimete then the "calorific value" of it can be found. By this means has been found that one gram of protein gives 4·1 Calories, o gram of fat 9·3 Calories, and one gram of carbohydrates 4·1 Calori So that weight for weight, fat produces over twice as much ener as proteins or carbohydrates.

Before we proceed further, let us describe these three kinds of fo a little more in detail.

Carbohydrates are so named because they consist of carbon, hydrog and oxygen only—the last two in the same proportion as in wat

Carbohydrates form the chief fuel for muscle contraction, and large quantities are therefore necessary in manual work. An average amount in the daily diet would be about five hundred grams. As we have seen each gram yields 4·0 Calories of energy, five hundred grams are equivalent to about two thousand Calories. In the body the carbohydrates are burnt up, yielding as end products carbon dioxide and water. The former is excreted by the lungs, the latter by the kidneys and the skin.

Fats contain the same elements (carbon, hydrogen and oxygen) as carbohydrates, but not in the same proportions. A fat has much more carbon and hydrogen in it, and less oxygen. For this reason a fat requires a large amount of oxygen to burn it up—in doing which much energy is released, more than double the amount from the same weight of carbohydrate or protein.

An average diet contains about one hundred grams of fat per day, yielding about nine hundred and thirty Calories.

Proteins (pron.: pro-teens), differ from both carbohydrates and fats, in that they contain nitrogen as well as carbon, hydrogen and oxygen. They are thus essential in building up protoplasm.

THE VALUE OF PROTEINS

So it is that the proteins not only act as fuels (producing 4·1 Calories per gram), but as replacers of worn parts of the machinery. This they do by virtue of the fact that in digestion they are broken down from highly complex structures to relatively simple amino-acids —the bricks of which, as we saw in Chapter I, protoplasm is composed.

Of these amino-acids there are about twenty which may be built up in all kinds of ways, so forming different proteins. Such differences are shown in the various tissues of the body, in animal and vegetable proteins, as in those of brain, liver and corn.

In order to build the various tissues of the body particular amino-acids are required, which must be present in the food. For this reason it is necessary for the food to contain not only sufficient quantity of protein, but the right quality of proteins. For instance, one amino-acid, *lysine* (pron.: lis-seen), has been found essential to growth, so that however much protein a child may eat, if it does not contain lysine, there will be a stunting of growth. Some proteins supply a better set of amino-acids on being digested than do others. For this reason the former are called proteins of first quality, the latter proteins of second quality.

To ensure this adequate supply of the necessary amino-acids, the best method obviously is to mix animal proteins, vegetable proteins and cereals, as in eggs and meats, beans and peas and bread. Again one comes back to the golden rule of a plentiful, mixed diet, which solves nearly all the dietetic problems of health. About

one hundred grams of protein is the average daily intake, yielding about four hundred Calories. The waste products are excreted as urea in the urine.

Adding these values together then, we find that an average diet will consist of :—

Proteins	100 grams	..	400 calories
Fats	100 „	..	930 „
Carbohydrates ..	500 „	..	2,000 „
	Total Calories		3,330

Salts, water and vitamins are also essential.

We are now in a position to understand the famous experiment of Atwater and Benedict in 1905, who put a man inside a chamber specially designed to measure the heat given off—a calorimeter. For four days this man lived in this strange home. The Caloric value of all his food was accurately measured, and compared with the heat given out from his body. It was found that the body works in exactly the same way as an engine as far as the energy exchanges are concerned—that the energy taken in equals the energy put out.

HOW WE BURN UP OUR ENERGY

It will be clear that the amount of work done varies enormously. That amount, however, which is done whilst at complete rest in bed after a night's sleep, and before taking any food, is an obvious minimum, and gives information as to what is known as the " basal metabolic rate." This rate is a measure of the amount of energy required to keep the body warm and the heart, brain and lungs alive —it is the minimum of vital energy exchange. Any increase of energy output is due to activity. Some people burn fuel faster than others, so that their basal metabolic rates are always abnormally high. These people soon burn up all their fat, and so lose weight and waste away. A person with a fever is always burning up his fats more quickly than normal. It is for this reason that a long fever leaves the patient so wasted and thin.

Taking any kind of food increases the metabolic rate, because of the energy necessary for digestion. But protein has a peculiarly marked effect in this way, known as its " specific dynamic action." Why or how proteins should cause this sudden increase in activity of the body remains an unsolved problem.

Let us now see what some common foods contain in terms of their proteins, fats and carbohydrates.

Bread—" the staff of life "—is made from wheat. This contains large quantities of starch, as well as some proteins, which are peculiar in that when mixed with water they form a substance *gluten*, which is sticky and is the basis of dough.

Dough is indigestible being a solid, heavy mass, but mix it with baking-powder or yeast, either of which produce gas bubbles, and the mass is made light and porous, forming bread.

Brown bread is made of wheat with the husks, which are removed in making white bread. These husks act as a mild laxative on some people, as well as containing traces of vitamin B.

WHY MILK IS AN IMPORTANT FOOD

Milk contains besides ninety-five per cent water, protein, fat, carbohydrate and vitamins, and is sometimes spoken of as "the perfect food." This is not quite true, since milk alone is too deficient in iron and carbohydrate for an active life—nevertheless it is invaluable as one item in a mixed diet. Milk can be clotted by rennet into "curds" of protein. These "curds" when acted on by bacteria form cheese, which is in consequence, a rich protein food. The fat of milk forms cream—the basis of the ordinary "ice" which is therefore a very nutritious article of diet.

Meats consist of protein and fat and water—varying of course, with the animal of origin. Roast beef gives about eight hundred Calories per pound. Pork has an even higher Calorific value.

Potatoes consist almost entirely of carbohydrate, salts and water. They have no protein. A pound of potatoes gives about four hundred Calories.

THE NECESSITY FOR VITAMINS

We must now describe the vitamins, and their relation to nutrition.

If an animal is fed on perfectly correct proportions of protein, fat, carbohydrate and salts, it does not thrive. In fact it soon stops growing, and eventually dies. This fact was first pointed out in 1880. From this year begins the study of the special food factors present in fresh food, which are essential to life. First, it was found that fresh butter contained some vital factor that was absent from lard—this substance was called a vitamin, and not one but many were found. Up till to-day nine or ten vitamins have been discovered. All are lettered in alphabetical order.

Vitamin A is soluble in fat, and is found in milk and butter, as well as green vegetables. Deficiency of this vitamin leads to liability to infection and nervous diseases, as well as night blindness which we mentioned in the last chapter. Chemically it is very closely related to *carotene*, the pigment responsible for the colour of carrots. This vitamin is essential for growth. Vitamin D is usually grouped with A, because it is so similar. In its absence bones fail to grow and rickets develops in children. The perfect development of teeth is impossible without vitamin D. This vitamin can be produced by the action of sunlight on the skin. Chemically a very complex substance, vitamin D can now be built up by the

chemist. It is found in all the foods containing vitamin A.

The vitamin B complex is found in the husks of rice and other grains. It has been divided into many closely related vitamins which have slightly different effects, the chief of which are called B_1 and B_2—both are necessary for growth. Yeast contains this vitamin in high concentration. It is also present in greens, milk and meat. Other vitamins B_3, B_4 and B_6, have recently been discovered.

Vitamin C prevents the disease, scurvy. This used to be rampant amongst sailors in the old days of sailing ships, when for months perhaps, the crews lived on salted meats, with no fresh food. Captain Cook first showed that scurvy could be prevented by taking fresh fruit. This vitamin is present in oranges and lemons, and other fresh fruits.

Vitamin E is essential for the reproduction of young in certain animals, probably including man. It is present in fats.

It will be seen that these vitamins are eminently desirable constituents of one's diet. But it should be borne in mind that as regards vitamins "enough is as good as a feast." In a reasonably mixed diet, there are sure to be sufficient vitamins present. In which case there is no point in taking more. On the contrary, it is thought that excess of vitamin can produce actual disease. Unless therefore the diet is deficient in these factors no benefit can be derived from taking large, extra doses of vitamins. The only point is to see that the diet is sufficiently varied, containing enough milk and fresh fruit.

THE ESSENTIALS OF ANY DIET

Let us summarize the characteristics which a diet must fulfil:

(1) It must be of sufficient Calorific value, about three thousand five hundred on an average.
(2) It must contain proteins, fats and carbohydrates, in correct proportions.
(3) Fresh vegetables and fruits are necessary, as well as milk, butter and eggs, to ensure adequate vitamin supply.
(4) There must be sufficient water and salts.
(5) Finally, it must be appetizing. For without this, all the other properties are null and void. Appetite produces a free flow of all the digestive juices. Without it the food cannot be satisfactorily absorbed into the body.

This problem of making food appetizing is the most difficult of a housewife's tasks. It includes good cooking, daintily served up dishes, pleasant company and conversation at meal times, and finally special foods designed to stimulate appetite. These are called condiments. Most people like some flavouring with their food, such as mustard, pepper, and salt. Except for the last of these three there is no food value in condiments, and their action lies in stimulating the taste-buds and creating a good flow of digestive

juices in the stomach in preparation for the food that is about to enter it. They are good when used in moderation, but in excess they may irritate and inflame the lining of the stomach.

Alcohol is another substance often taken as an appetizer—some times in the form of a cocktail before a meal, or as beer and wine with it. The " cocktail habit " is undoubtedly bad, for concentrated alcohol is a strong irritant to the stomach, and repetition of this gastric " insult " is resented by the organ in question, which at length fails to respond, and becomes inflamed, losing its digestive juices altogether. But beer, with about four per cent alcohol in it, and a bitter substance, is undoubtedly a good appetizer, and without harm, if taken in moderation.

THE EFFECT OF ALCOHOL ON THE BODY

When alcohol is taken it is in part absorbed into the system from the stomach itself—a very unusual occurrence. Flowing in the blood some of it is burnt up, some dilates the capillaries of the skin, causing flushing, and sweating, some goes to the brain where there is no true stimulation of mental capacity, but only a release from higher qualities such as self-consciousness, judgment, etc. The result is, that after alcohol one thinks one is being so much more clever than one is. It is this unfortunate spectacle that makes teetotal friends say such hard things afterwards.

Actually alcohol can act to some extent as a food, and be burnt up in the body. Brandy is given to sick people partly for this reason, and partly for the stimulating " bite " of it in the mouth. But in " a glass of bitter," it is the bitter taste which does just as much good as the alcohol in stimulating the appetite. Whisky and gin have nothing to recommend them from the physiological point of view.

WHAT HAPPENS TO THE FOOD WE EAT?

We have seen what food is, and what different kinds of food there are. We must now follow what happens to this food when we put it into our mouths, and swallow it. What exactly is the process of digestion? What is its object?

The final destination of the food on your meal table is the tissue cells of the body. For these must be fed and kept in good trim. But it is a long and complicated journey from your mouth to them, and during it the food has got to be radically changed.

In order that food shall be absorbed into the blood stream, it must first be broken down into its simplest forms. This is what digestion means—breaking up the highly complex chemical food molecules, into very much simpler substances, which can finally pass through the wall of the gut into the blood, where we will follow them later. This breaking up of food molecules is brought about by enzymes, or ferments, of various types which are found in the mouth, stomach and

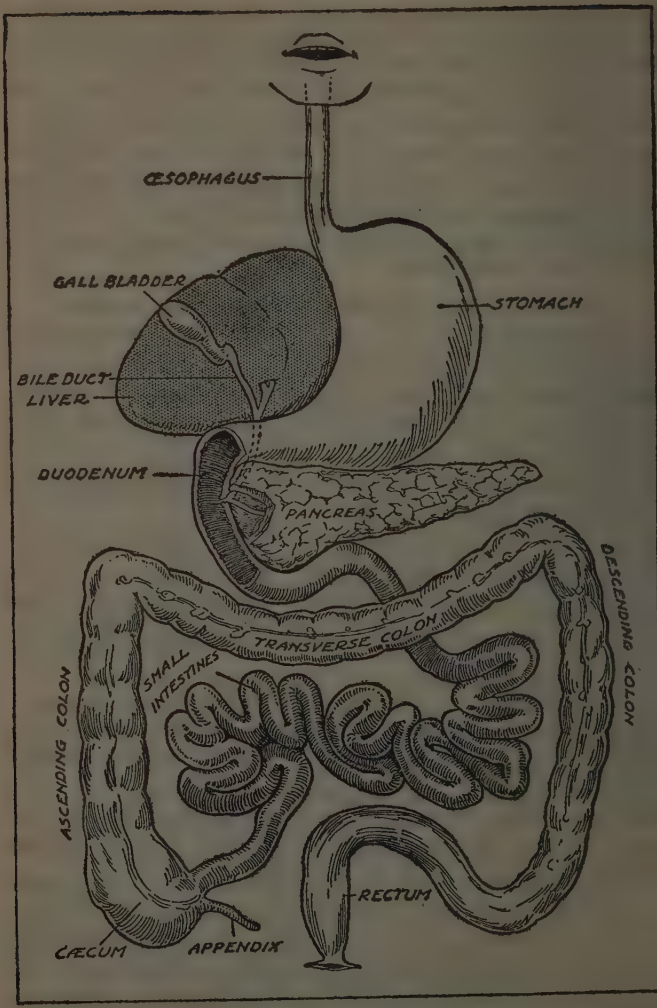


Fig. 1. *Diagram (slightly simplified) of the alimentary tract.*

intestine. Bacteria also play a part in the large gut or colon. Each enzyme breaks down its particular food, that is to say there are some for the proteins, many different ones for starches, and so on.

All these enzymes have to be regulated so as to act on the food in their correct order and at the right time, for some act in the mouth, others in the stomach and intestine. Food, therefore, when finished with in one part is pushed on to the next, for the next stage of digestion. The study of the process of digestion consists therefore, of the action of these various enzymes, and the way in which the food is passed along the gut at the right time.

OUR NINE YARDS OF INTESTINES

The result of digestion is that all foods, however complex they were in the beginning, with the exceptions of water and salts which undergo no change, are broken down. Before we describe this process we will describe the apparatus which brings it about—the *alimentary tract* (Fig. 1). In primitive animalcules, the digestive organ consists of a penetration into the skin, forming a hole into which food is directed and subsequently digested. This description if much exaggerated, applies to the alimentary tract of man, which is, as far as the tissues of the body go, really outside rather than inside. It is simply that it forms a hole, right through the body to the other end.

This canal or tube in man is about nine yards long; most of this length being in the form of coils of intestine inside the abdomen. First is the mouth where enzymes first get at the food and start their work. From here it passes down, through the pharynx, into the *œsophagus* (pron.: ee-soff-ag-us) or gullet. This tube passes down through the chest, lying in front of the spine and behind the windpipe and heart, until it pierces the diaphragm to enter the stomach.

HOW THE ALIMENTARY TRACT IS BUILT UP

This is a large bag which, in the standing position hangs in a J-shape. Its end passes through a ring of muscle the *pylorus*, into the *duodenum* (pron.: du-o-dee'num), which is continued into the long coils of small intestine. This finally runs into the large intestine at the cæcum. It is at this point the appendix is attached. The large intestine is not slung freely on a sheet (the *mesentery*, *see* Fig. 3), like the small intestine, but is closely bound to the posterior wall of the abdomen. It takes a peculiar course, running first upwards on the right (the *ascending colon*), then across from right to left (the *transverse colon*), and finally downwards on the left (the *descending colon*). After forming a loop in the pelvic basin, the *sigmoid colon*, it becomes the *rectum* where waste food products pass to the outside again.

Under the microscope, the walls of the alimentary tract are all found to be built on the same plan. The whole tube is lined (*see* Fig. 2), by a mucous membrane. This consists of *epithelial cells*

resting on fibrous tissue and a thin layer of muscle known as the *muscularis mucosæ* (pron. : mu-ko-sigh). Mucous membranes secrete. The simplest mucous membrane just secretes the slimy mucus we have mentioned before. But in the parts of the alimentary tract special digestive secretions are necessary, and for this purpose glands are found in the mucous membrane. These glands are tiny tubes of cells, which branch until they look like a microscopic bunch of

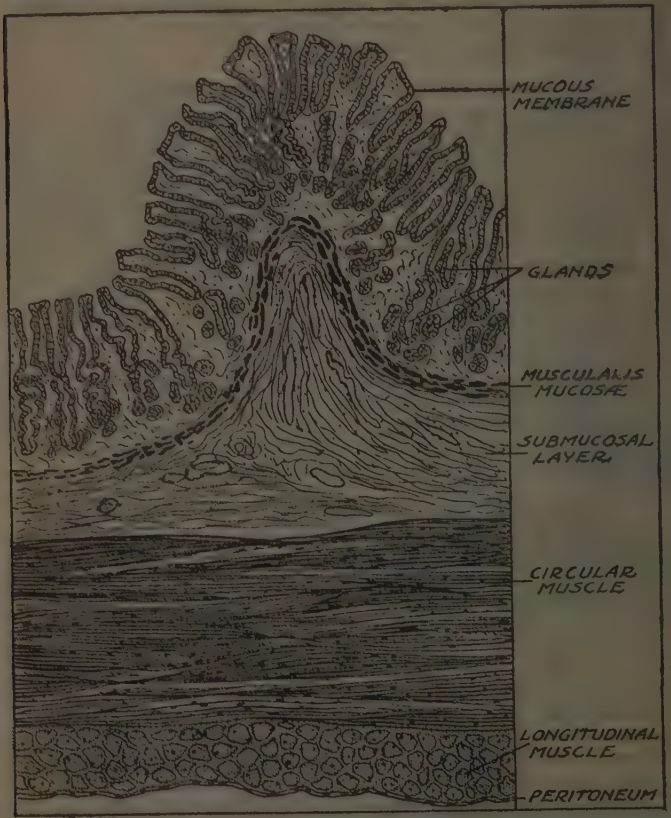


Fig. 2. A section (enormously enlarged) of the wall of the stomach, showing glands and muscle layers.

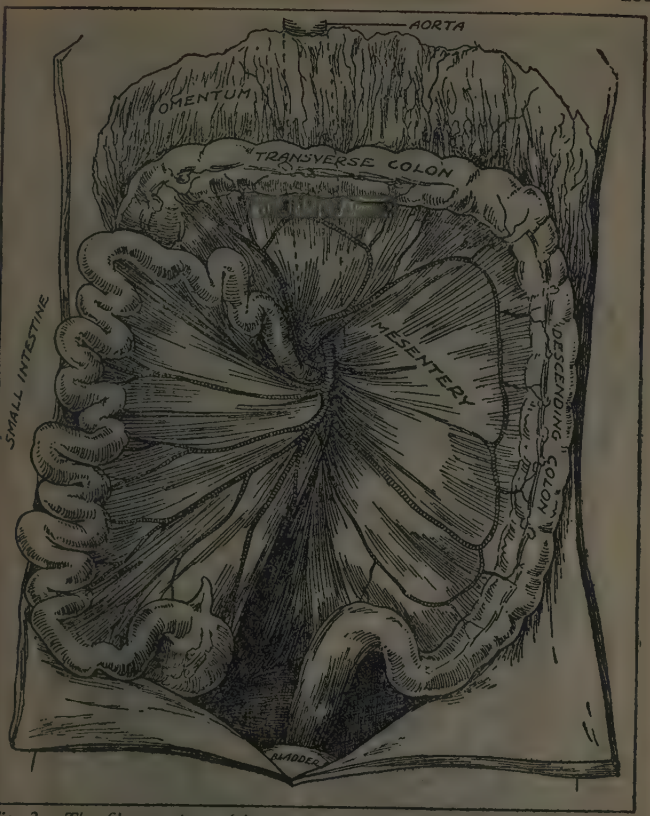


Fig. 3. *The fibrous tissue (the mesentery) which carries the blood vessels to the intestines.*

grapes. This glandular epithelium is very marked in the stomach.

Below this inner glandular layer of the tube is a submucosal layer of fibrous tissue, rich in blood vessels from which the glands make their secretions. Outside this again is a double layer of smooth or unstriated muscle, the inner layer being circular (round the hole so to speak) the outer longitudinal. In the submucosal layer, and between the two muscle layers are scattered nerve cells and fibres. Outside all these layers is a shiny *serous* membrane the *peritoneum*.

When we described the aorta we named the cœliac, and superior and inferior mesenteric arteries which carry blood to the different parts of the intestine. These arteries approach the gut along a layer called the *mesentery* (Fig. 3), which is attached along the front of

Fig. 4. The lower part of the alimentary tract showing the gall-bladder and part of the omentum, the apron covering the intestines.

Fig. 5. A lever lobule. In the centre is the intralobular vein which receives blood from the small vein outside. Bile flows in the opposite direction into the small bile duct.

the aorta, where it picks up the blood vessels and carries them to the intestinal walls. The veins from the gut collect finally into the great portal vein seen in Fig. 10, page 130. This runs up to the liver, the blood coming into intimate contact with the liver cells, before it finds its way into the inferior vena cava, and so back to the heart.

The nerve supply of the alimentary tract is from the vagus nerve. Piercing the diaphragm with the œsophagus, it ramifies all over stomach, small intestine and most of the large gut, the remainder of which gets its parasympathetic supply from nerves coming from the sacral region of the spinal cord. As usual, vagal action is balanced against the sympathetic system of fibres. These we have already seen coming from the thoracic part of the cord, forming the sympathetic trunk, from which rise the splanchnic nerves (Fig. 8, page 127). They pierce the diaphragm and spread out in the walls of stomach and intestine. Stimulation of the vagus in general enhances all the activities of digestion, that is, it makes the digestive glands secrete and the muscle contract, so moving on the food. On the other hand, stimulation of the sympathetic relaxes the muscle, makes the glands dry up, and closes the valves or sphincters which exist, for example, at the end of the stomach in the pyloric region.

These opposite actions are quite consistent with the general rule that the vagus excites building up processes, digestion being

essentially a stage of building up the body, whilst the sympathetic excites the opposite processes. For if muscular exertion is indicated, obviously digestive processes must be slowed down.

So far we have described the intestinal tube alone. But early in the life of the embryo two small hollow buds appeared in the region of the duodenum. These grew out until quite separate from the gut, developing at their ends into two most important digestive glands—the liver and the pancreas (Figs. 4 and 6). Both these empty into the duodenum by ducts. The liver (Fig. 4), the largest gland in the body lies in the upper right-hand side of the abdomen. It is "dull on percussion," and although it cannot be felt, since it is tucked under the ribs, it can be mapped out quite easily in this way if you like to try. Under the microscope its cells are seen (Fig. 5), to be collected into lobules. Blood is borne by the small branches of the portal vein which we saw entering the organ, to the outer sides of these lobules, whence it seeps through in between the liver cells to the central vein, which joins with others to flow into the hepatic vein, and so to the inferior vena cava. From these liver cells also come the small ducts which unite to form larger bile ducts—the largest of which, the common bile duct, finally joins the duct from the pancreas to open into the duodenum.

The *gall-bladder* is a sac where bile is stored when not being used. It is connected with common bile duct by a special duct of its own.

The *pancreas* lies across the front of the spine, behind the stomach (Fig. 6). Microscopically it consists of masses of tubular glands

Fig. 6. The pancreas, and the organs around it.

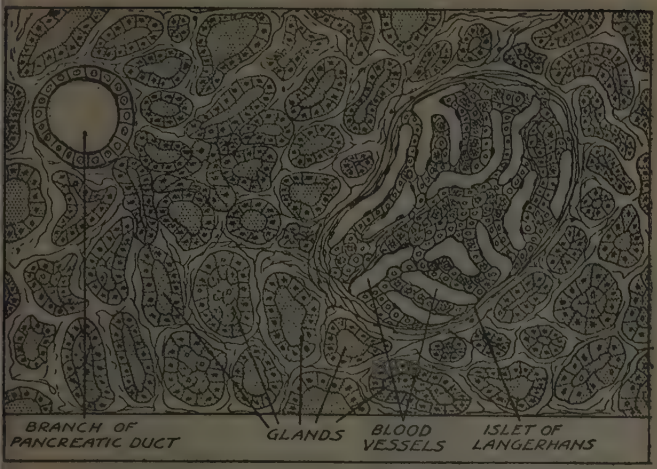


Fig. 7. A microscopic section of the pancreas.

whose secretion enters the pancreatic duct, so flowing into the duodenum and the *islets of Langerhans* which secrete *insulin* (Fig. 7).

Let us now see what happens to food in the alimentary canal.

First of all, what is eating? In the mouth food is treated chemically and mechanically. Enzymes from the salivary glands commence to break down starches, the teeth crush the food into smaller pieces, breaking up the tough fibres and cells which consist in large part of starchy substances, so that the saliva can get at them. Different teeth have different work to do, and it is interesting in this connection to see how structure varies with function.

A tooth consists of three main parts—a crown, neck, and roots which fix it firmly in the jaw (so giving the dentist so much trouble). Cut across (Fig. 8), a tooth shows an outer coating of a hard substance known as enamel. This is for crushing tough foods. Inside it is a layer of firm dentine, which contains fine nerve fibres. Within this again is the pulp cavity, containing the main blood and nerve supply to the tooth. When infection gets into the pulp then comes that throbbing toothache, which unfortunately so many of us have experienced. The tooth is set in a layer of firm, bony cement.

The front teeth are designed for cutting. They are therefore sharp edged and flat. The canines, or eye-teeth, are designed for tearing and rending. They have, therefore, very long roots setting them firmly in the jaw. In animals they form the fangs bared in anger.

Fig. 8. *Section of a tooth in its socket.*

In man they have shrunk to the size of the front incisors, from disuse. The back premolars and molars are designed to grind like millstones. They have flattened surfaces, therefore, with ridges which interlock so grinding food very small. The shapes and positions are shown in Fig. 9.

Every one knows how the presence of food in the mouth causes saliva to flow. This it does by stimulating the taste-buds.

This secretion comes from three salivary glands, the *parotid*, *submaxillary* (pron.: sub-mak-sill'ary) and *sublingual*, whose ducts open into the mouth (Fig. 10). The last two open under the tongue and may be seen by raising the tongue, but most easily seen is the opening of the parotid gland on the cheek, opposite the first upper molar tooth.

Saliva consists of over ninety per cent water, the rest being *mucin*, traces of potassium and an enzyme *ptyalin* (pron.: ti'al-in). Its main use, therefore, is simply that of moistening the food. The mucin makes the food slippery and so easy to swallow. The ptyalin gets mixed up in the food mass where it begins its task of breaking down the complex starches. This process continues in the stomach for some minutes after the food has been swallowed.

The salivary glands do not secrete continuously. As soon as food is put into the mouth, they commence secretion. With moist foods such as a juicy steak the submaxillary and sublingual glands secrete only a small amount of saliva, the parotid practically none at all. But with a dry food, there is a plentiful watery flow.

In the course of a day the salivary glands of man secrete nearly two pints of fluid for the purpose of lubricating the food and mouth. In animals which feed on green stuff, containing a high proportion of

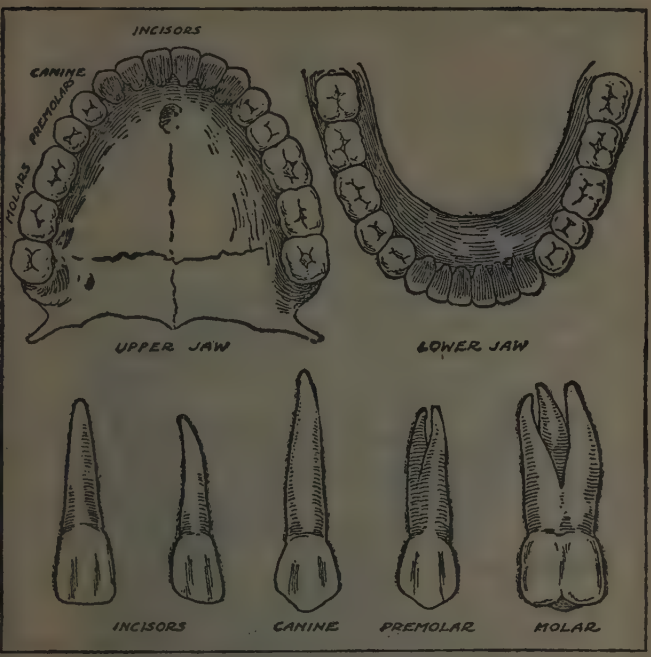


Fig. 9. The different shapes of teeth.

starch, this amount is very much greater. Because of their accessibility much work has been done on the salivary glands to try and answer the general question of how glands secrete. When a salivary gland is active there is an enormous increase of blood-flow through it—perhaps to as much as eight times the normal.

From this blood the fluid of the saliva is derived—but how? Does it just seep through into the gland ducts, or do the cells of the gland have to pump it out, so to speak? That it cannot be a question of simple filtration, is shown by a very beautiful little experiment of Ludwig's, in which the pressure in the duct of the gland is shown to be greater than the blood pressure in the carotid artery. And since filtration depends entirely on a difference of pressures, according to this, fluid should be flowing in the opposite direction. Moreover, it has been definitely shown that the secreting salivary glands perform mechanical work in transferring fluid from blood vessel to

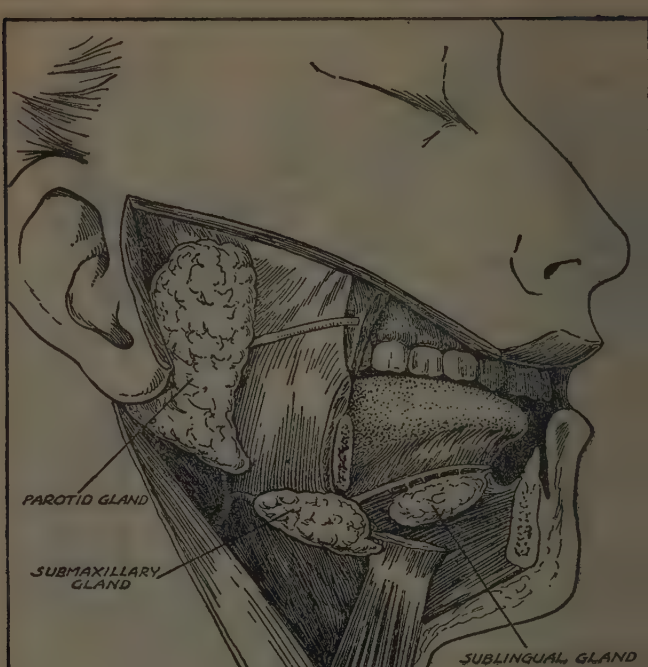


Fig. 10. *The position of the salivary glands.*

gland duct. This is actually done by certain granules inside the cell themselves. When the gland is at rest, the cells are filled with these *zymogen* granules. These disappear after activity, indicating that the secretion was being stored in them, inside the cell, until required. When the gland (Fig. 11) is stimulated, these granules take up fluid, swell, and those near the surface of the duct, burst so that their secretion eventually finds its way into the mouth.

Moistened by saliva, crushed into small pieces by the teeth, the mass of food is now rolled into a fairly compact ball by the cheek and tongue, and placed at the back of the mouth ready for swallowing

Fig. 11. *Salivary glands before* (left) *and after secretion* (right).

This complex act (Fig. 12), is one again with which familiarity has bred contempt. During it the food passes from our consciousness, and we become unaware of it. First there is the cessation of mastication—the ball of food being placed on the back of the tongue. Then the soft-palate—the muscular part of the palate which divides mouth from nose—is raised, so separating completely the two cavities. This is essential in order to prevent the food being pushed back into the nose. This sometimes happens if one is made to laugh whilst drinking a cup of tea. In laughing, the passage from pharynx to nose is open, and if tea is being swallowed at the time, then it passes back along the nose—a most embarrassing situation.

At the same time then, as the nasal passage is closed off, the larynx rises slightly. Now the tongue moves suddenly upwards and backwards, thrusting the food into the pharynx. Once thus started the

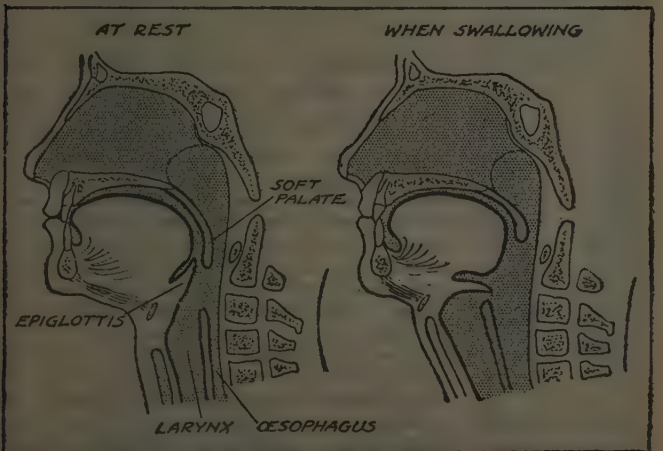


Fig. 12. *The movements of tongue and throat in the act of swallowing.*

whole process of swallowing must now complete itself. The food is now passing through that part which is common to both alimentary and respiratory tracts. We have seen how the upper, nasal, end of the respiratory tract is closed off. Even more important is the closure of the lower part—the entrance to the larynx. The larynx rises up so that it gets tucked under the back of the tongue as this thrusts the ball of food into the pharynx. The muscles round the opening of the glottis contract, and close the opening.

The *epiglottis* (pron.: eppy-glottis), which forms a leaf-like lid to the top of the glottis, lying behind the root of the tongue, seems to take but a small part in the protection of the larynx.

The food passes through this critical part of its journey in a matter of a second or two, entering the œsophagus, where it is lost to consciousness. Studies of swallowing in this region have been extensively carried out by X-raying a person swallowing a barium paste which is opaque to X-rays. This special "meal" can then be followed accurately right down the œsophagus, through the chest into the stomach. With fluids the œsophagus relaxes completely so that within a few seconds, the fluid has flowed all the way through the thorax into the stomach.

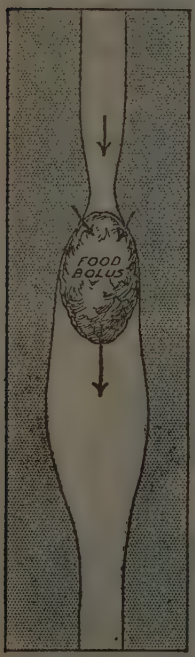


Fig. 13. *How a ball of food is pushed along by a wave of peristalsis.*

At the bottom of the œsophagus, where it passes through the diaphragm and enters the stomach there is a *sphincter*. This consists of a band of circular muscle, which, on contracting, squeezes the muscular tube tight so blocking it, and preventing any food passing. Often the food is delayed, therefore, at this point until the sphincter relaxes and a wave of *peristalsis* sweeps it into the stomach.

Peristalsis is the peculiar method by which food is moved along the whole intestine. It consists (Fig. 13), of relaxation of the muscular tube in front of the food bolus with contraction behind. The result is that the food is squeezed along by this wave of contraction that may flow for inches.

Sometimes, however, this orderly process of swallowing does not proceed so smoothly, and we all know the unpleasant sensation of "a crumb going the wrong way." This means that a small particle of food has slipped past the barriers at the top of the glottis, into

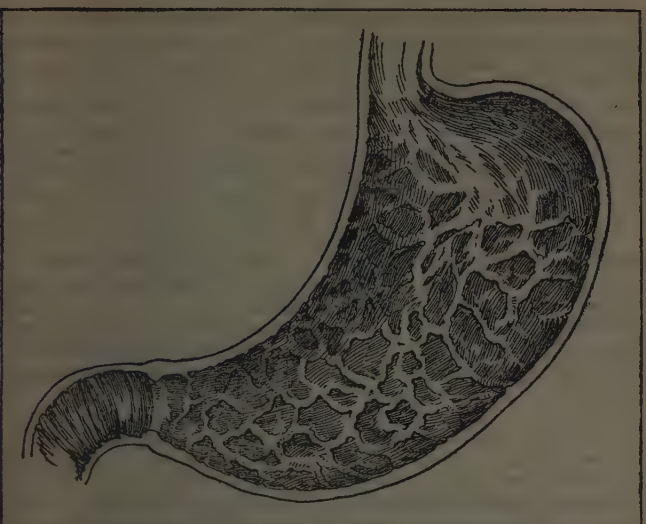


Fig. 14. *A section through the stomach showing its lining.*

the larynx. As we saw before, the larynx is very sensitive to stimulation from within, so that the bit of food sets up a violent cough reflex from this area, and with it a most distressing tickling in the throat. Usually as a result of this coughing, the intruding crumb is quickly expelled, and sent down the œsophagus, but not before some very unpleasant moments have elapsed. It is only on the rare occasions when these accidents occur, that we appreciate the skill of an arrangement which makes them so unusual. It is interesting in this connection to notice that breathing stops automatically whilst swallowing is going on. If you hold your breath until you feel you must take another, then swallow, definite relief is obtained for another few seconds. This is simply because the act of swallowing has inhibited the urgent desire to breathe.

Swallowing, then, is mostly a reflex, although, of course we can swallow voluntarily, but this is not usually so. If the pharynx is sprayed with cocaine the sensory nerve endings are dulled and do not respond to the stimulus of being touched, so that the reflex is not set up. The control of the reflex is in the vagus nerve, which rules nearly all of the alimentary canal. If both vagi are cut, the swallowing reflex disappears.

The food now enters the stomach. This organ (Fig. 14), is of variable shape, depending whether it is full or empty, but usually it hangs like a large J from below the diaphragm on the left side. If it is filled with a substance containing barium, it can be examined under the X-ray. The normal stomach is then seen to be in constant movement. Rings of contraction (peristalsis) flow from the top half, the cardiac part, down to the lower half, the pyloric portion, pushing food through the pyloric sphincter into the duodenum. The pyloric sphincter is another ring of muscle very similar to that at the end of the œsophagus. Its function is to hold back food in the stomach until it is completely acted on by the enzymes of the gastric juice, letting it through for digestion in the duodenum.

In the wall of the stomach are special glands which secrete gastric juice in a similar manner to the salivary glands. Gastric juice is not the same as saliva however. It contains hydrochloric acid, a ferment; pepsin, which digests proteins; a special ferment of digesting milk—rennin, which forms milk curds in the stomach; and plenty of the slimy mucin for lubricating the food mass.

HOW THE GASTRIC JUICES BREAK UP FOOD

The gastric juice has been studied in man by what is known as a "fractional test meal." In this test one swallows a fine rubber tube which enters the stomach, the other end remaining in the mouth. With a syringe on the end the juice of the stomach is sucked out, and a special gruel meal given. This is withdrawn gradually, a small quantity every fifteen minutes, and the specimens analysed chemically. The result throws light on the state of the stomach glands. The first historic study of the stomach was however, done by an American doctor named Beaumont, who carefully observed the reactions of the stomach in a man who, as the result of a wound, had a hole between his stomach and the outside. This was about 1830.

The action of gastric juice depends on the hydrochloric acid and the *pepsin* in it. The former acts on sugars, chiefly splitting them into simpler forms, and prevents growth of bacteria in the stomach.

The pepsin, which works only in acid surroundings, and is therefore largely dependent on the hydrochloric acid, acts on proteins. Protein consists of enormous molecules, so large that they may verge on visibility under the microscope. Pepsin acts on these molecules, breaking them down into smaller molecules, called *proteoses* and *peptones*, in which stage they pass through into the duodenum.

Carbohydrates are for some time acted on in the stomach by the ptyalin from the salivary glands, until the hydrochloric acid penetrates the food mass and destroys the ptyalin, itself splitting the carbohydrates still further.

Fats also are acted upon slightly in the stomach, but most of fatty digestion occurs later.

It should be noted here, that the mucous membrane of the stomach secretes a substance known as *intrinsic factor*, which combines with substances in the food containing *extrinsic factor*. These two are essential to the adequate ripening of blood cells. The result of their combination—the *hæmatinic factor*—is stored in the liver.

In pernicious anæmia intrinsic factor is found to be lacking, so that the patient's liver contains no proper hæmatinic factor. For this reason administration of normal liver by supplying the missing factor cures the anæmia.

EFFECT OF EMOTION ON DIGESTION

The secretion of gastric juice is controlled by nervous and chemical methods. Ingenious work on dogs by Pavlov, the Russian physiologist, revealed many facts on this subject. By making a hole to the outside from a dog's œsophagus, it was so arranged that the dog ate and swallowed, but the food dropped out of the neck before reaching the stomach. Such a meal was called a "sham feed." Pavlov also made a small pouch of stomach secrete to the outside, then measuring the fluid secreted after food. With "sham feeding" he found that gastric juice with a high acid content, continued all the time the dog fed—although no food entered the stomach. By showing food to a hungry dog he found that the stomach secreted even more juice than if the food was actually placed in the stomach. These experiments proved that gastric secretion was controlled by reflexes. On cutting the vagus nerves both of these stimuli failed to cause any secretion, so that the vagus must be the nerve along which the stimuli passed to the stomach. The sympathetic system also supplies the stomach, having an inhibitory effect on its secretion and movement. In great emotion gastric juice almost dries up.

CHEMICAL CONTROL OF THE GASTRIC JUICES

But there is also the chemical method of control. There is evidence, from various experiments, that a substance, absorbed from the pyloric part of the stomach into the blood stream is carried to the glands in the other parts of the stomach, so stimulating them to secrete gastric juice. This process may go on for a long time, so continuing the quicker but shorter effect from nervous stimulation.

For the gastric juice so secreted to act adequately on the food in the stomach there must be proper mixing. This is obtained through the movements of the stomach. As soon as food enters it, peristalsis commences at a rate of four to five per minute. Rings of contraction flow down the stomach pushing the food towards the pylorus which is at first closed, so that it gets pushed to and fro, and becomes thoroughly mixed with gastric juice. Soon the pylorus opens, and the food is squeezed through into the duodenum. If fluid is taken into the stomach it tends to follow the right border, or lesser curvature,

and flow quickly through into the duodenum. But with solid food this does not happen. In this case, the stomach takes about two hours to empty, unless there is some obstruction to the food. The pylorus opens when food in the stomach has become thoroughly acid from being mixed with gastric juice, and when the peristaltic contractions get very large. Sometimes the contents of the duodenum are regurgitated back into the stomach, especially after a fatty meal has been taken, for fat lies in the stomach longer than other foods.

Sometimes, although the stomach is empty, strong contractions occur. These contractions give rise to "hunger pains," which can be rapidly relieved by taking food. These pains are curiously related to the sugar in the blood, tending to occur if this is low, as often happens in hungry people. Hunger itself, without pain, is related to the tone of the stomach muscle. Good tone, good appetite, is a truth concerning the stomach. People with lax stomachs rarely have good appetites. With good tone goes plenty of gastric juice.

WHAT CAUSES VOMITING?

Vomiting is an act that results from stimulation coming from many parts of the body. Over-eating with a distended stomach is certainly one common cause, but quite often it occurs as a reflex from elsewhere. To some people a disgusting sight or smell is sufficient to produce vomiting. At the beginning of such a disease as appendicitis, reflex vomiting is very common. The act of vomiting consists of expulsion of the contents of the stomach. Following a feeling of nausea, and secretion of saliva into the mouth, the diaphragm suddenly contracts down hard on to the stomach. The upper entrance to the stomach being open, its contents are pushed out by the squeezing of the diaphragm and muscles of the abdominal wall : the stomach itself hardly contracts at all.

The centre for the act of vomiting is in the medulla oblongata, near the origin of the vagus nerve, and the respiratory and vasomotor centres. To this spot come the impulses from various parts of the body—most often from the stomach, or from the back of the throat, both sources of origin for the stimulus to the act of vomiting.

THE USES OF EMETICS

The sensitivity of the stomach to irritation is ingeniously used when somebody has swallowed a poison. For some time this will lie on the stomach, so that a drug which will induce vomiting will rid it of at least some of the poison. Such a drug is called an *emetic*, the commonest of which is ordinary salt and water. Mustard is another. The strongest of these emetics is called *apomorphine*—a drug closely related to morphia. This acts on the vomiting centre in the medulla, producing the act of vomiting from this part of the reflex arc, not from the stomach, so that it can be given by injection.

CHAPTER XI

THE FINAL PROCESS OF DIGESTION

THE acid food, partially digested by the glands of the stomach, is now passed on into the next part of the gut, the *duodenum* (pron.: duo-dee'n-um). Here the *liver* adds its bile, and the *pancreas* (pron.: pan'-kry-ass) its own secretion to the food mass, whilst the contact of acid food on the mucous membrane of the duodenum automatically closes the sphincter muscle at the pylorus.

The secretion of the pancreas is most essential in carrying on the process of digestion commenced in the stomach. If food is taken, within a few minutes there is a flow of pancreatic juice through the duct which opens into the duodenum, following which, a steady outpouring continues until the stomach is empty. The actual stimulus to the pancreas is acid entering the duodenum, though in the first instance nervous impulses from the vagus nerve take a part. But since the secretion of the pancreas is not so urgent as that of the mouth and stomach, nervous regulation is very much less prominent than is chemical.

For the most part, pancreatic secretion is regulated by a chemical messenger called *secretin*. The acid in the food from the stomach, in company with bile from the liver, is absorbed through the wall of the intestine into the blood stream, whence it flows round to the pancreas, stimulating the secretion of juice (Fig. 1). As long as acid food is coming from the stomach, secretin is formed and sets off on its journey to the pancreas via the blood stream. This process stops automatically as soon as the stomach is empty.

Pancreatic juice is alkaline, due to a large amount of sodium carbonate in it. So that it soon neutralizes the acid mass of soft food which comes from the stomach. This at once stops the action of pepsin. In pancreatic juice are three powerful ferments, one for the digestion of each of

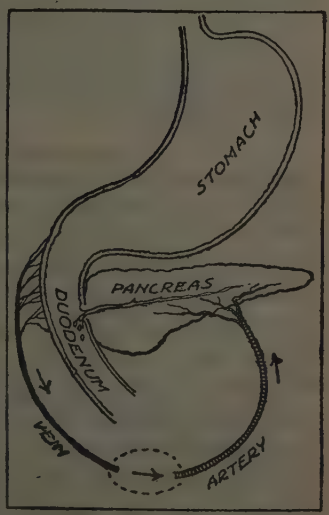


Fig. 1. How secretin flows from the duodenum to the pancreas stimulating the flow of pancreatic juice.

three main kinds of food—proteins, fats and carbohydrates. *Trypsin* acts on proteins, *lipase* on fats, and *amylase* on carbohydrates.

Trypsin is stored in the pancreas in an inactive form which does not break down proteins, and only becomes active when it meets another enzyme which is found in the gut. By this method the pancreas avoids digesting itself.

Trypsin digests the mixture of proteins which come through from the stomach in various stages of digestion, splitting them up into simpler products. Lipase simply splits fats into glycerol and fatty acid. In an alkaline medium, these fatty acids unite to form what are chemically, really soaps. These soaps are in structure very like ordinary bath soap which consists of fat combined with alkali. This action of lipase is very much increased by the presence of bile.

The amylase acts on starches and sugars, in the same way as the saliva—splitting them into simpler forms, but not yet into a form which can be absorbed by the gut.

We saw how the secretin formed in the duodenum flowed to the pancreas and stimulated it to action. A very similar substance also flows to the liver, producing a flow of bile. At first the bile which enters the intestine comes from the gall-bladder, where it has been stored ready for use. Later, it flows straight from the liver. The nervous system plays a very minor rôle in the control of the flow of bile. Probably it takes part only in contraction of the gall-bladder, so expelling some of its stored bile, and not in the actual secretion of bile from the liver at all.

BILE AND ITS USES

Bile consists of a mixture of the following substances : bile pigments, bile salts, cholesterol, mucin, and water. The bile pigments are bilirubin (red bile) and *biliverdin* (green bile). The bilirubin, as we saw in Chapter VI, was formed from destroyed red blood corpuscles. This is excreted by the liver, and on its way is oxidized thus changing to green—that is, to biliverdin—which finally enters the duodenum. Sometimes when one is sick the vomit is coloured green. This means that the sphincter muscles of the stomach are opened and that biliverdin can pass through into it. The biliverdin passes down the intestine, being changed into *stercobilin*, a brown pigment—the normal colour of excrement or *fæces* (pron.: fee-sees).

The mucin of the bile is responsible for its sliminess and viscosity. The concentrated bile from the gall-bladder is more viscous than that which comes straight from the liver.

The bile salts are most important from the point of view of digestion. They are complex substances, whose action in the duodenum is to quicken up the digestive processes, so that food is more rapidly absorbed into the body. This particularly applies to fats, for the bile salts have an emulsifying effect on these, forming

soaps which consist of much finer particles than oily "neutral" fat globules, so that the pancreatic lipase has easy access to do its work. These bile salts are themselves later re-absorbed from the intestine and pass back to the liver via the portal circulation whence they are again excreted, thus forming a "circulation" of bile salts. Since fresh bile is also being continuously formed, it is difficult to see why the amount of bile salts is not being steadily increased, or what stops the body from becoming "a pillar of bile salts."

Cholesterol (pron. : kol'ester-oal) is one of the mystery substances of the body. We still know very little about its metabolism. It is excreted by the liver in the bile. It is related to the hormones of sex. It increases in the blood in pregnant women, and in some kidney diseases; but its function so far is not well understood.

THE CAUSES OF JAUNDICE

Blockage of the bile ducts from the liver sometimes occurs—as, for example, by gall-stones formed in the gall-bladder and caught in the bile duct. This gives rise to "yellow" jaundice, since the bile pigments are prevented from leaving the liver, and so re-enter the blood stream and stain the tissues. Jaundice, however, can be caused simply by the formation of too much bilirubin when there is excessive breakdown of red blood cells, so that, even though the liver is healthy, it cannot excrete all the bile pigment presented to it.

Passing down the small intestine, the food now comes under the full action of all the pancreatic ferments, as well as the secretions from the glands of the small intestine itself. This alkaline fluid contains, amongst other ferments, *erepsin*, which has the power of acting on the partly broken down proteins and finishing off the process to the stage, in which the protein foods are finally absorbed. This erepsin cannot act on pure proteins, but only on those that have been attacked by pepsin or trypsin beforehand.

Intestinal juice also contains an enzyme—*invertase*—which splits up the sugars into three absorbable forms—*glucose*, *fructose* and *galactose*.

HOW BACTERIA CAN AID DIGESTION

So far, we have described the various enzymes in their work of splitting up food. There is one digestive agent we have omitted—bacteria. In Chapter I we denied the popular idea that bacteria were necessarily enemies of man. In the intestine we find them actually working for health. In the stomach the hydrochloric acid prevents bacteria from flourishing, but lower down the intestine, after the acid has been neutralized by the alkaline pancreatic and intestinal juices, the environment is suitable. So that in the lower part of the small intestine bacteria are numerous. In the large intestine enormous numbers of them are found.

These bacteria serve a purpose, which is chiefly to break up

indigestible cellulose particles in the food. *Cellulose* is the substance that forms the tough walls of plant cells. In the herbivora (animals such as sheep, that feed on plants only) provision must be made for digesting this tough cellulose, for all the most nourishing material lies enclosed within these indigestible walls. In some herbivora—the ruminants—the grass passes first to a paunch in which bacteria develop, and dissolve the cellulose, after which the mass is regurgitated into the mouth, where it undergoes the process known as "chewing the cud," finally passing into the stomach for digestion.

WHERE BACTERIA ARE ESSENTIAL TO LIFE

Another mechanism for dealing with cellulose is a long, large intestine. The more an animal eats plant food, the longer is its large intestine. Here it is that the bacteria act on cellulose that has been too tough to be digested in the stomach and small intestine. Moreover, in some animals at least, these bacteria are essential to life. For if new-born chicks are fed only on bacteria-free food, they die. Add some of the droppings of a hen, and the chicks thrive.

This action of bacteria on cellulose produces gases, such as marsh gas and carbon dioxide. These are usually re-absorbed from the intestine by the blood flowing through its walls. But if there is an amount of cellulose, the gas produced is excessive, and flatulence or "wind" results. Sugars are acted on by bacteria, producing lactic acid. There are even particular "lactic acid" bacilli. These bacteria, if encouraged, probably kill off others to make room for themselves. This fact gave rise to an idea once favoured by a famous continental professor, that the secret of long life lay in the regulation of the intestinal bacteria by taking by mouth cultures of lactic acid bacilli. Unfortunately, this professor himself died at an average age, and his idea has not been accepted. Nevertheless there is no doubt that the lactic acid bacilli can help some people with digestive troubles.

HOW BACTERIA BREAK DOWN PROTEIN

Bacteria also act on protein. Here they cause putrefaction or decay, but usually proteins have been so completely digested by the processes we have already described that little is left on which the bacteria can act. If an excess of protein is taken, this may not be so, however, and putrefactive substances are produced. It is these that are responsible for the odour of fæces. A similar process is occurring in the gut as that which occurs when meat "goes bad."

Finally, in describing this process of digestion in which every kind of tissue is broken down, it has probably occurred to you to ask What stops these enzymes, or ferments, from digesting the intestine itself? In most cases this remarkable immunity of the gut from the enzymes it produces seems to be linked up with the fact that in its

walls are found anti-enzymes which neutralize the enzymes. This does not apply to the method in the pancreas which we have already described. It is interesting to notice that intestinal worms, such as tapeworms, contain quantities of these anti-enzymes, so being able to resist the digestive juices whilst living in the small intestine.

We have now described the chemical processes of which digestion in the intestine consists. But we noted at the beginning of our description of digestion that the food must be moved on in such a way that the various juices act at the right time.

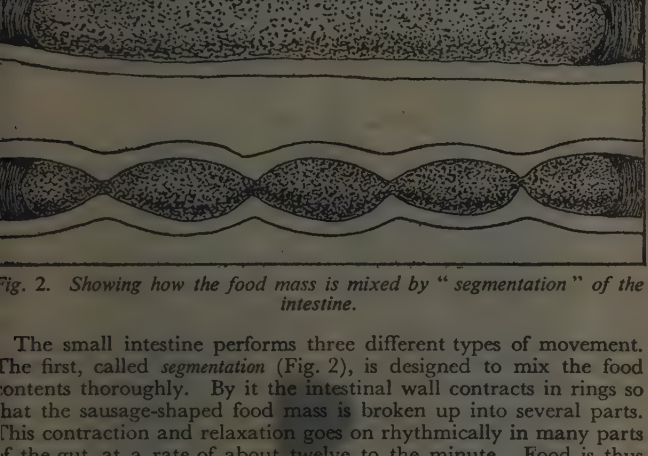


Fig. 2. Showing how the food mass is mixed by "segmentation" of the intestine.

The small intestine performs three different types of movement. The first, called *segmentation* (Fig. 2), is designed to mix the food contents thoroughly. By it the intestinal wall contracts in rings so that the sausage-shaped food mass is broken up into several parts. This contraction and relaxation goes on rhythmically in many parts of the gut, at a rate of about twelve to the minute. Food is thus churned about and thoroughly mixed with the digestive juices.

The next movement is less obvious; small portions of the gut are seen to sway to and fro like the pendulum of a clock. This again aids in thorough mixing of the food contents. *Peristalsis*, as in the œsophagus, moves on food from one part to another. As usual, the wave of peristalsis may consist of a ring of relaxation in front of the food with a ring of contraction behind, squeezing it along. But there is also another kind of peristalsis in which food moves much more rapidly in a "rush" which travels along the whole length of the small gut. Sometimes anti-peristalsis occurs, by which food is pushed in the opposite direction. This takes place in the duodenum

usually, forming an additional measure for adequate food mixing

We have noted previously how stimulation of the vagus nerv increases intestinal movement and secretion, whilst stimulation o the sympathetic nervous system has the opposite effect. Th movements of segmentation and peristalsis both occur in the sma intestine, however, even if it has been deprived of all its nerv supply : the secret of rhythmic contraction lies in the muscle itsel

At the end of the ileum, or small intestine, is another sphincter— ring of muscle which surrounds the ileum just as it passes into th cæcum (Fig. 3). This sphincter behaves unusually. Unlike th others we have described, it does not relax on stimulation of th vagus nerve, though it contracts on stimulation by the sympathetic This would seem to indicate that its special function is to sto regurgitation of food from the cæcum back into the small intestin

We have already described how bacteria inhabit the large intestin and part of the small intestine. As far as digestion is concerne

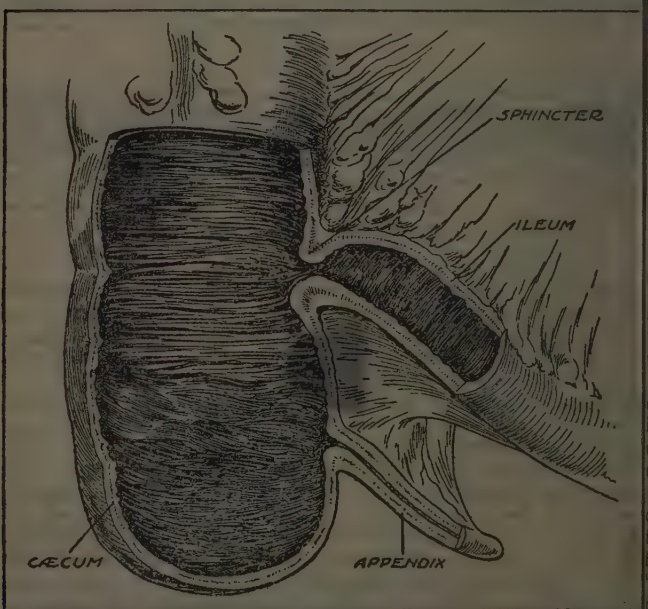


Fig. 3. *How a sphincter muscle in the intestine regulates the passage o food from the ileum to the cæcum.*

Fig. 4. *Microscopic view of goblet cells lining the large intestine or colon.*

the function of the large gut is mostly as a container of these active bacteria. In animals which eat flesh alone, therefore, the large intestine is relatively unimportant as compared with that of herbivora, or plant eaters. Since man eats a mixed diet, the large intestine is of intermediate importance in him.

Scattered through the mucous membrane of the large gut are "goblet" cells. These are shaped (Fig. 4) like little goblets, filled with a clear material, mucus. This substance serves as a lubricator for the firm masses of food residue. It is also thought to discourage the growth of bacteria to some extent. The large intestine cannot absorb much in the way of nourishment. Water is absorbed there, so that the fluid mass in the cæcum and ascending colon becomes firm in the descending colon and rectum. Glucose can be absorbed in small quantities—but proteins not at all.

The large intestine is, on the other hand, mainly concerned with excreting substances from the body. Calcium is excreted chiefly in this way, and also in the urine. Iron, which is absorbed in the duodenum, is almost entirely excreted into the large intestine. Such drugs as bismuth also take this route, even if given by injection.

In about five hours after it has been swallowed, food reaches the cæcum, into which it is pushed by peristalsis (Fig. 5). At first fluid, it soon becomes solid. In about twelve hours this solid mass has been pushed round to the descending colon on the left. Curious "mass peristaltic" movements occur in the large intestine, which result in the contents being pushed on very rapidly.

The act of expelling unabsorbed waste products from the body through the lower end of the digestive tract is known as *defæcation*.

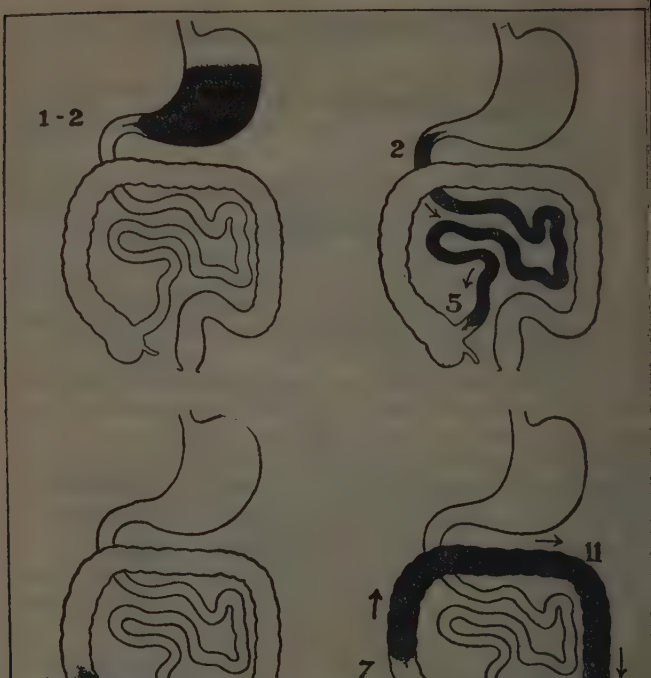


Fig. 5. *The course of a meal through the intestine. The figures indicat the approximate hours after swallowing.*

When the fæces, or waste matter, collect in the rectum (the las part of the digestive tract), they distend the walls. This gives rise t a reflex, which ends in a contraction all along the descending colo on the left side of the abdomen. Sometimes even the transvers colon is affected. By this contraction, fæces are expelled in stron peristaltic movements. Around the opening of the canal on th surface of the body is another sphincter or ring of muscle. Thi retains the fæces that lie in the rectum when distended, refle peristalsis is set up, this sphincter relaxes and the fæces are expelled

One of the sources of origin of this reflex is, strangely enough, the stomach. It is because of this that often the desire to open the bowels occurs soon after taking a meal. In some people this reflex becomes exaggerated and they get a form of diarrhœa in which the bowels are moved every time they take any food. This does not mean, of course, that the food has "passed right through them," as some people think. The centre for the reflex which lies in the spinal cord may be affected by the emotions very readily. Extreme fear acts in this way, producing the desire to empty the bowels.

WHY PURGES STIMULATE THE BOWELS

Purges are drugs taken with the intention of hastening the progress of the food residue. This they can do by stimulating the muscle of the intestine directly, causing increased movements of peristalsis. The same effect is obtained by "salts," which "act" by attracting water to the gut. The increase of bulk stimulates the walls to contract.

Throughout the whole intestine the process of peristalsis is the device whereby food is moved on from one part to another. Simple as it is, sometimes peristalsis goes wrong. Then pain is produced. We have already seen how strong, probably abnormal, peristalsis of the stomach produces "hunger pains." In quite a number of people, a similar spasm occurs in the muscle of the large intestine, producing dull aching pain. If there is severe constipation, then the bowel contracts harder and harder to move on the obstruction, until the pain of "colic" is produced. By this method of pain the bowel informs its owner when all is not working as smoothly as it should.

We have seen that in the normal process of digestion there is really very little food which passes on from the small intestine to the large. Only the tough plant cellulose does so, and the day's diet of many people contains very little of this. In view of this fact, the fæces are surprisingly bulky. This is due to the rather strange truth that perhaps the larger part of fæces comes, not from food residue at all, but is formed by the gut wall itself. In this connection it is interesting to note that even starving animals pass fæces.

A DEFECT OF MODERN DIET

Fæces consist mostly of masses of dead bacteria mixed with mucus and bile. Of course, if a large amount of fruit and vegetables (which contain much cellulose) has been taken, then a proportion of this is passed out as fæces. This bulky cellulose distends the gut, and in some people acts as a laxative, by stimulating peristalsis. It may do this to the extent of producing diarrhœa. It has even been suggested that constipation is so common nowadays for the simple reason that we take too little cellulose in our diet. Cellulose is tough, and foods are so refined in civilized diets that all tough particles are removed, and the bowel is not stimulated.

Digestion achieves its object then, in the small intestine to which we shall now return in order to watch the next stage of absorption. The food has been broken into small particles. These are to be transferred from the intestine on the one hand, to the blood stream on the other. This process, known as absorption, has never been fully explained. The laws of physics seem to fail us here. Perhaps it is because we have still more to learn about them. Or perhaps there is something in absorption which lies beyond them. But how is it that this blood serum, which is exactly the same as the blood

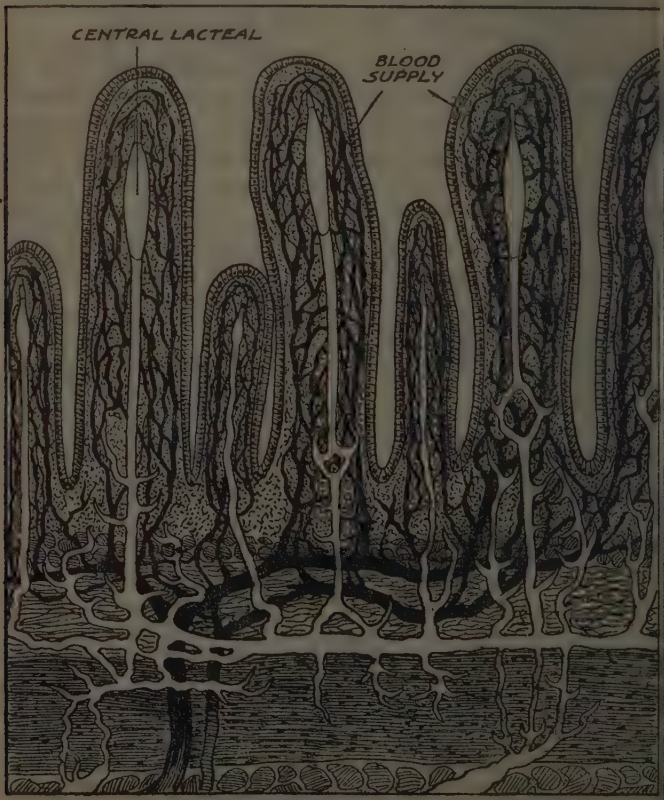


Fig. 6. How food is absorbed from the intestine. (*See text.*)

n the wall of the gut, is absorbed if it is placed within the intestine?

The apparatus for absorption is shown in Fig. 6. Here large inger-like processes may be seen protruding from the wall of the ut. These are called villi. Each *villus* is covered by tall columnar pithelium which are the actual absorbing cells. Between the tall illi are hollow crypts similarly lined. In the centre of each villus s a tube, known as a *lacteal*, which runs down to join up with a etwork of small lymphatic vessels permeating the intestinal wall. n the villus itself are lying scattered muscle fibres which, when ontracted, squeeze the central lacteal, so "milking" it of its ontents. But this is not the only route that absorbed particles can ollow. For near the tall columnar absorbing cells, lies a network f capillary blood vessels, ready to take what comes their way.

These villi have been examined under the microscope whilst ctually engaged in the process of absorbing food. In this way hey can be seen to contract one by one, as the muscle inside them milks" the contents of the central lacteal on to the lymphatics in he gut wall. From here these lymphatics eventually enter the horacic duct, which, as we have already seen, opens into the veins.

HOW FATS ENTER THE BLOOD STREAM

When "neutral" fats are split up into fatty acids and glycerol by he pancreatic secretions, they are absorbed by the villi. If the bdomen is opened two or three hours after a fatty meal, all the ymphatics which flow from the wall of the intestine can be seen ike white streaks, converging towards the thoracic duct. These white streaks are the transparent lymphatics, filled with microscopic at particles. Flowing along this strange route, the fat eventually enters the jugular vein, flowing into the blood with the lymph hrough the thoracic duct. It is surprising to realize that the fat of the milk and cream which we drink is going to enter our blood through a little channel in the left side of the neck.

Under the microscope the fatty acids can be seen flowing through the absorbing cells of the villi into the central lacteal. During this process (*see* Fig. 7) fatty acid and glycerol mysteriously combine again to form the "neutral" fat. The presence of bile in the intestine is in some way essential to this process of fat absorption. Normally, about ninety-five per cent of the fat is absorbed in the small intestine in this way. But if bile is absent, then a large quantity of fat is passed on. So that in jaundice, where bile is prevented from entering the intestine, stools are large and full of fat.

Carbohydrates, we have seen, are all broken down by the various digestive juices into simple sugars. These are now absorbed by the villi of the small intestine. They do not pass into the lacteals, like the fats, but into the capillaries that flow beneath the absorbing cells, and so by the portal vein, to the liver.

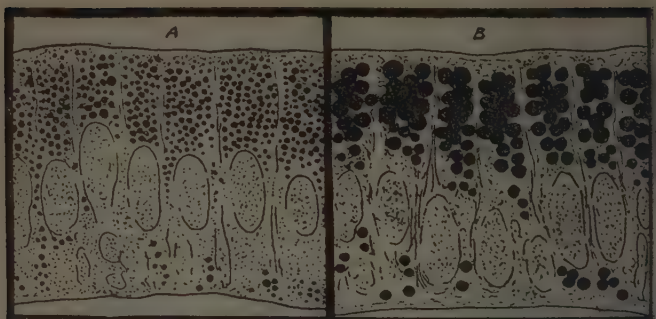


Fig. 7. The appearance of the cells lining the intestine before (a) *and after* (b) *a fatty meal.*

Proteins we described as being broken down in the digestive processes from highly complex structures to relatively simple substances called amino-acids. These, too, are absorbed into the blood of the capillaries in the villus, and not into the central lacteal. Normally, no protein as such enters the blood. Sometimes, however, for some reason this does occur, particularly in children. If a foreign protein of food evades digestion and gets absorbed as such it often gives rise to sickness, diarrhœa, and sudden wheals and rashes on the skin which irritate intensely. "Food poisoning" is often due to this event and not to any disease germ.

WHY PROTEIN FOODS ARE SO VALUABLE

After a meal of protein there is a marked increase of these amino-acids in the blood. These "bricks" for building up proteins are thus sent round the circulation, where they come into contact with all the various tissues of the body. These have been undergoing a certain amount of wear and tear in the course of their duties, during which they have developed a need for "spare parts." These they select from the variety of amino-acids which flow past them.

In this way protein foods repair tissues as well as supplying fuel.

After this selection of amino-acids has been carried out, some are left over. Also the tissue proteins themselves, in the course of wear, have broken down into amino-acids. Both these kinds of amino-acids are now carried to the liver, where they are especially treated and deprived of their nitrogen portion.

This leaves the rest of the amino-acid molecule with carbon, hydrogen and oxygen only. This portion is eventually made up into a suitable fuel and is fed to the tissues for burning. In this way, after having supplied necessary "spare parts" to the tissues, the

remainder of the protein food is used as fuel. None is wasted.

The liver builds up the nitrogen part of the amino-acid into a substance called *urea*, which is passed into the blood stream and is excreted by the kidney in the urine. Can one but admire so ingenious a mechanism for making use of all available protein?

The further fate of these various foods, after their absorption into the blood of the body, is a part of the subject of "special metabolism." But since it is all one continuous train of events, and is so vitally linked to digestion, we shall consider the subject briefly in this place.

At the beginning of Chapter X we described very briefly the energy exchange of the body, and how there was a balance of energy taken in against that given out by the body. Here we are proposing to follow the absorbed foodstuffs and see in a little more detail how these energy exchanges, and repairs in the case of proteins, occur.

At the outset it must be made quite clear to the reader that we are entering into the most complex sphere of organic chemistry—and that is saying a lot. This branch of chemistry which actually investigates the chemical reactions of living tissues is known as bio-chemistry (the chemistry of life). Of necessity, therefore, we must be prepared to find many problems with no solution.

WHY THE LIVER IS ESSENTIAL TO LIFE

Let us first briefly follow absorbed amino-acids which have entered the blood stream. These we saw were selected by various tissues, chiefly by those which are growing rapidly, for these need amino-acids, not only to replace worn out parts, but to build new. How this is actually done is not yet clear. "Can the body itself make amino-acids?" is an often-asked question. Some of them it can, but others, and these essential to life and growth, it cannot make. In the previous chapter we have seen, for example, how necessary it is to have one amino-acid—lysine—in the diet for the healthy growth of the young chick. This means that the body cannot manufacture lysine for itself, however much it needs it.

Now the result of the breaking-up of amino-acids in the body by the liver is that the nitrogenous substance urea is formed.

Urea can come from two main sources, therefore. Either it may be made from amino-acids from the food or from those produced by breakdown of the tissue cells of the body. If a dog is given a large meal of protein, half the nitrogen of that protein food is rapidly excreted. This means that half the protein eaten is being used as fuel, and only half for replacing the proteins of the tissues. This formation of urea is performed by the liver, a process known as *deamination*. What actually happens is that the nitrogen of the amino-acid is taken out in the form of ammonia which (since it would be a poisonous alkali if left) is immediately made harmless by combining with carbonic acid of the blood. This combination is

the substance urea. If the liver is diseased, little urea is formed. Urea is normally present up to two to three per cent in the urine. Sometimes bacteria act on it by splitting the urea into ammonia and carbonates, thus producing the ammoniacal smell which results when urine has been allowed to stand. This process is the opposite of what occurs in the liver.

In the muscles is a substance, *creatin*—one of the "extracts" which comes out in the gravy from lean meat. This substance, slightly changed, also finds its way into the urine, particularly after exercise. The more muscle, and the more exercise, the more this creatin is excreted, and this is especially marked if there is not enough carbohydrate in the diet to provide fuel for the muscle to burn. So in the urine there is a chemical clue to how muscular you are.

HOW URIC ACID IS FORMED IN THE BLOOD

The nuclei of cells are composed of very special kinds of protoplasm containing what are known as nucleo-proteins. When digested by the ferments of stomach and intestine, the protein part is split up in the manner which we have already described. But the "nucleo" part splits into phosphoric acid, a sugar, and a substance belonging to a group called purines. It is this last, the *purine*, which in the blood forms uric acid. It has been well said that "more nonsense has been written about uric acid than any product of animal metabolism." Here we find that it is the final product in the body formed as the result of breakdown of nuclei in the food. But like urea, it is also formed from the nuclei of the tissues which wear out and die. So that the uric acid of the blood increases after hard muscular work, as well as after eating foods such as liver or sweetbreads, which are particularly rich in nuclear material. Uric acid also increases in the blood in diseases where the white cells of the blood multiply exceedingly. These cells are destroyed and from their nuclei eventually comes uric acid.

EFFECT OF URIC ACID ON GOUT

Gout, a disease that so often seems to affect prominent English politicians, is always accompanied by a rise in the amount of uric acid in the blood. In fact, the disease is essentially due to the inability of the body to deal with its uric acid. Instead of being excreted, it is deposited in the joints—particularly that of the big toe, where it causes acute pain and swelling.

It will be realized that uric acid is one of the waste products of the body. It is not surprising, therefore, to find it in the urine where it sometimes forms a pinkish sediment, especially in hot weather when the urine is very concentrated.

We have already traced the absorption of fats as far as their entrance into the blood by the thoracic duct. What happens to

this fat next? Through the blood it is carried all over the body, where it is picked up by various cells. A large portion of it goes into storage as "depot fat," where it awaits the call to be used. About one-tenth of the weight of an average person is due to this reserve of fat in the body. Half of this lies beneath the skin, the rest being packed inside the abdomen and between muscles.

Fig. 8. The omentum as it appears on opening up the abdomen.

Fig. 9. Illustrating how the omentum—the apron of fat—covers the organs of digestion.

In the abdomen there is a most peculiar sheet of fatty tissue, the *omentum* (Figs. 8 and 9), which hangs down from the lower border of the stomach just like an apron covering all the abdominal organs. It consists of a network of blood vessels within a mass of fat cells. Apart from this function of storing fat, the omentum has a peculiar activity, which has gained it the title of "policeman of the abdomen." For wherever there is any trouble there you find the omentum. For example, if the appendix becomes inflamed, the omentum wraps itself around the diseased area, isolating it from the other organs. Many lives have been saved by this mysteriously mobile apron of fat.

Different animals have rather different fats in their bodies; for example, mutton fat is much harder than beef fat. This is due to the different fatty acids—mutton fat containing more stearic acid, and beef oleic. But if one animal is persistently fed on the fat of another its own fat will gradually change. So that if a wolf was fed for a very long time on mutton fat, then eventually all the fat beneath its skin would become mutton fat.

One must remember, however, that the fat of the body is not derived only from fat taken in the food. If this were so a reducing diet would be very easy. That fat can be formed from carbohydrate foods is a truth well known to farmers, who fatten their stock on such foods as maize which contain very little fat in them. Possibly a little fat is also formed from the proteins of the diet.

The great use of this storage fat is as a source of energy for the body. We saw how a gram of fat yields over nine Calories if burnt up, whilst protein and carbohydrate only yield about four. Obviously, therefore, fat is a most efficient form of storing energy. Protein and carbohydrate are never stored in the body in great quantity, owing to limited suitable accommodation, but there is plenty of room for large fat stores.

If the body is starved, or in a fever, the fat stores give up their contents to be burnt in the body, and wasting soon occurs. Fat also serves another purpose, that of keeping the body warm. It is a bad conductor of heat, and the warmth of the body is prevented from leaking out into the air by this covering beneath the skin. Since women have more fat beneath the skin than men, they can expose themselves to cold without feeling it as much as the leaner male. That this is so is shown by the lightness of their clothing. Women's open necks and short sleeves would make any man shiver.

When the demand comes, these fats are mobilized into the blood stream and are taken to the tissues to be burnt. But fats by themselves burn, as we know, with a smoky flame, and in being burnt in the body, produce poisonous products called *ketone* bodies, which if allowed to accumulate result in serious illness, even unconsciousness or coma. These consequences are avoided in the healthy body by burning sugar at the same time.

We have already seen that the liver plays an important part in dealing with the amino-acids in digesting protein. It also plays a part with the fats. We saw that the supplies of reserve fats were finally mobilized for use by the tissues; but in their storage form they are not suitable as fuel, so that first they are carried to the liver, which " desaturates " them, thus making them more combustible, and then discharges them into the blood again in a new form. Some of this new fat is taken into cells and burnt as fuel whilst some of it, of a very special kind, is actually built into the protoplasm of the cell. This occurs particularly in the brain, the cells of which have a very high proportion of fatty substances in them.

THE FATE OF SUGAR

Carbohydrates, as we have already seen, are broken down and absorbed as simple sugars, of which the most important is glucose, or grape sugar. After a meal, therefore, the amount of sugar in the blood rises (Fig. 10). This occurs rapidly, when sugar is eaten, but drops again within two hours. It is perhaps remarkable that greater variations do not occur, but the body has a very delicate method of adjusting the level of blood sugar.

As absorbed from the gut, sugar enters the portal vein which takes it to the liver. This wonderful organ, which seems to have no limit to the number of tasks it can perform, again comes into play and alters the sugar from glucose to a starchy substance called *glycogen*, which is then stored inside the liver cells themselves. But in spite of this, some glucose leaks through the liver into the main blood stream, where more of it is deposited in the muscles, in the process also being turned into the form of glycogen. If the glucose enters the blood stream very rapidly, then liver and muscle fail to collect it all and store it so that it passes over in the kidney into the urine.

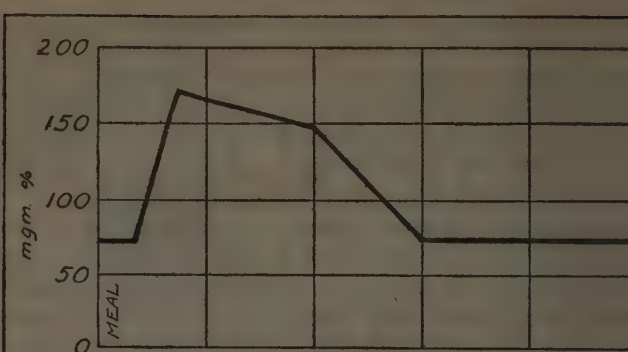


Fig. 10. *Graph illustrating normal changes in the blood (sugar) following meal.*

In starvation this store of glycogen in the liver is very soon calle upon; in a day or two this organ has lost all its glycogen, and th muscles begin calling out for fat from the depots as the next best fue

When we described the pancreas, we mentioned that it contains two different kinds of cells—those that secreted the enzymes into th intestine, and the islets of Langerhans which secreted a hormon insulin, into the blood stream. These islets are small masses cells with a plentiful blood supply. Scattered all over the pancrea they manufacture insulin and secrete it into the blood stream whe it enables the tissues, especially muscle, to use up the sugar presente to them. It also aids in turning the glucose presented to the liv into glycogen, the form in which it is stored. This glycogen readily turned back to glucose and passed into the blood again whe needed. These two processes of building glycogen from glucos on the one hand, and turning glycogen into glucose on the othe are continually going on in the liver, depending on the need of th body for sugar and the amount of glucose in the blood. The high the blood sugar the less is there a demand on the liver, and the sug remains in the liver as glycogen.

The muscles of the body also contain glycogen, formed from th blood sugar with the aid of *insulin*. It is in this form that the sug is burnt as fuel when muscle contracts.

If the sugar in the blood rises above about ·18 per cent, sug appears in the urine. Up to this level the sugar in the blood is he back; above this threshold value it is excreted by the kidney into th urine. Anything which raises the level of the blood sugar wi

herefore, cause sugar to appear in considerable quantities in the urine.

In diabetes, owing to a lack of insulin, the sugar in the blood cannot be used by the muscles and other tissues, so that although this precious substance increases in the blood the cells may be dying from lack of it. There is a death in the midst of plenty. The word diabetes means "running through," which describes the fate of sugar taken by such a person. It runs through the body without being used. Supplying insulin is like giving a hungry man the key to a food store, for now the tissue cells are able to use the glucose.

It will be realized how vital is the rôle which insulin plays in the process of digestion and absorption of our food.

THE DISCOVERY OF INSULIN

As long ago as 1889 it had been found that a dog whose pancreas had been taken out died with a very severe form of diabetes, but it was not until 1922—after many false starts—that the triumph of discovering and preparing the chemical substance from the pancreas was achieved, by Banting and Best, in Canada. At once they set to work on dogs with diabetes, and gave them doses of this new substance called insulin. There were many difficulties and dangers to be overcome before it was safe to try it on human beings; but this final step was eventually taken, with world-wide success.

The insulin secreted in the healthy body tends, as we saw, to lower the level of sugar in the blood. When this level gets too low, then one becomes irritable; hunger pains may even begin in the stomach. These are all indications that a meal is needed. This, when taken, soon raises the level of the blood sugar, following which, good temper is restored, and in place of emptiness and hunger pains there is that pleasant full feeling of contentment which is the sign of a good meal.

HOW SMOKING AFFECTS THE SUGAR IN THE BLOOD

Even smoking has an effect on the blood sugar. With each cigarette a slight rise regularly occurs, only to fall when the cigarette stump has been thrown away, a fall which gives rise to the feeling of needing another. This is how the "chain" habit starts.

But insulin is a product of one of the endocrine glands, and as such plays an intimate part with all the other similar glands of the body, such as the thyroid, adrenals and pituitary. We shall describe its relations to these glands in the chapter on the chemical messengers of the body. The front part of the pituitary gland plays in fact, an important part also, in the regulation of the blood sugar. It may even be that it controls the islets of Langerhans in the pancreas, thereby playing an important rôle in the production or cure of diabetes. These are further fascinating realms for exploration by the pioneers of medical research.

We have now followed the proteins, fats and carbohydrates to their

various destinies in the body. The most striking point about them all is how different is the fate of protein-foods to that of the fats and carbohydrates. Theoretically the body could live on proteins alone, without either of the other two, since the proteins are a source of fuel as well as spare parts for the wear and tear of tissue cells. Actually, this is not true because all cell protoplasm has an element of fat and carbohydrate in it, and so cannot exist in their absence.

But another contrast in the fate of the different foodstuffs is brought out when we look at the food reserves of the body. As reserve food for storage, fats stand predominant, with their high energy content which can be released on demand. Carbohydrates come next, since they can be stored in the liver as glycogen. If food is short this is the reserve first emptied, before the fats are called upon. However, the small supply of glycogen is soon exhausted.

Protein cannot be stored at all. Either the animo-acids are used up by the tissue cells or they are deaminated by the liver to form urea. There exists, therefore, no reserve supply of spare parts in the body's machine.

CHAPTER XII

THE WORK OF THE KIDNEYS

When the body has burnt its fuel, it has to get rid of the cinders. When it has used up the various kinds of foods in the way we have just described, it has to rid itself of the broken bits left over. This process is called excretion.

There is more than one way of doing this. For instance, the lungs excrete water and carbon dioxide from the body, as we have already seen. The skin excretes water in large amount—a process we described as sweating. Then the large bowel, or colon, also acts as an excretory organ. Certain metals of the body such as calcium, so vital to bone formation, are excreted by this route. But the main organ for excretion of waste products is the kidney. This organ adds the final touch to the story of the foodstuffs which begins in the mouth and stomach, is continued in the tissue cells, and finally ends in the urine, a fluid formed by the kidney.

Urine, therefore, is a very complex fluid. Its composition is very variable for it depends on the quantity and quality of the food taken in, as well as the amount of water lost by skin and lungs. But urine is always a yellow fluid, sometimes slightly cloudy. The more concentrated it is the deeper the colour. When one has been taking a lot of hard exercise with profuse sweating, the water which is excreted by the kidney is much diminished, so that the substances of the urine become concentrated, including the yellow

pigment in it, which now gives it a deeper colour. Conversely after drinking a large quantity of water, the urine becomes pale.

Sometimes the urine of normal people is cloudy. This is especially likely to be so in those who take vegetarian diets, for these foods give rise to alkaline urines containing some phosphates. Animals which live on green stuff, therefore, usually pass cloudy urine.

WHY THE URINE VARIES IN WEIGHT

One of the most important properties of urine is its *specific gravity*. This term applies to the relative weights of equal volumes of urine and water. Every one knows that a small glassful of mercury weighs very much more than an equal quantity of water. This is because its specific gravity is much greater than that of water. The weight of any substance is due to the attraction of the earth, which exerts a force known as gravity.

Weight is simply a measure of this force of attraction. Now different substances are attracted by different amounts of force. Water is attracted by a certain force which is taken as a standard. But mercury, or oil, or urine, are all attracted by their own special forces, known as their specific gravities. This consists therefore, of their weight compared with that of an equal volume of water. Water has a specific gravity of one thousand. Urine has a specific gravity of about one thousand and twenty—that is, it is heavier than water. This is because it contains dissolved substances. These substances are the result of the chemical changes in the tissues of the body. After sweating, when the urine becomes concentrated, the specific gravity rises, perhaps to a figure of one thousand and forty. After drinking large amounts of fluid it may become almost like pure water, with a specific gravity of one thousand and two.

HOW DEEP BREATHING AFFECTS THE URINE

In describing the blood, we mentioned its reaction as being slightly alkaline, and how there was a very special arrangement of "buffers" designed to prevent any acute change in this reaction. Now blood and urine are very closely related, for all that the kidneys do is to take the blood which passes through them, and by a process of selection, make urine out of it.

The reaction of the urine in man is usually acid. This is because in an ordinary mixed diet, substances which are finally broken up into acid particles predominate. Such substances are proteins containing sulphur, and sweetbreads, etc. Vegetable foods, on the other hand, although they contain acids are turned to alkali in the body. It is rather a strange thought that the sourness of a lemon, which is mostly due to citric acid, is going to become an alkali with the opposite effect on the urine. Another unexpected fact is that the blood should be alkaline, whilst the urine which is built up from

the blood, is acid. But it is actually by excreting these acid parts that the blood is kept alkaline.

Another way of altering the reaction of the urine from acid to alkaline is to breathe in and out deeply. This sounds an astonishing thing to say, but we know enough now to understand how this works. If we breathe out rapidly we get rid of carbon dioxide from the blood. Carbon dioxide when dissolved forms carbonic *acid*—which although weak, is an acid. The blood now becomes short of acid, but it must not alter its reaction, so the kidney keeps back the acid particles which come to it instead of passing them into the urine, with the result that it becomes alkaline, whilst the blood retains its usual reaction. This is a very pretty example showing how lungs, blood and kidney all work together for the body's good.

WATER INTOXICATION!

Now let us examine the urine more in detail, and see how some of the foods we have described in the last two chapters end their wanderings in the body.

About fifty ounces of urine are passed in the day, on an average. This contains about two ounces (sixty grams) of solid material dissolved up in it. The rest of it is water. We have already seen how the amount of water excreted by the kidney depends on the amount taken in, as well as the amount excreted by lungs and skin during the day. This sounds very simple, but of recent years it is being realized that the regulation of water balance in the body is a wonderful process, the complexity of which is not fully understood.

Nearly forty ounces of water are excreted in the day in the breath, skin and the fæces, quite separately from the kidney. In some diseases the excretion of water is upset and "water intoxication" may set in, a state not unlike alcoholic intoxication. Water may be stored in the body to some extent, usually lying between the cells. But such supplies as are stored in this way do not last long. If the body is short of water, the tissues soon find they have an insufficient supply, the blood gets too concentrated and thirst arises.

Sometimes the tissues attract water abnormally, causing "dropsy" so that the patient swells with water, in spite of which he is tormented by thirst owing to the fact that there is not enough of the precious fluid in the blood itself. Enough has been said to show that the water balance is not as simple as it was once thought to be. Probably there is a nervous centre concerned with this job in the brain, and there is definite evidence that secretions from the pituitary gland below the brain can affect the water exchange of the body.

In every diet there is a certain amount of common salt or sodium chloride. Even if one does not add salt to the diet there is some in most foods. Some of this sodium chloride passes out of the blood through the kidney into the urine. The sodium chloride taken in

the diet, enters the blood and is selected by the tissues, the rest being excreted by the kidneys. Usually, therefore, the blood is salt.

It is very interesting to note in passing, that the salts of the blood plasma form a solution which is remarkably similar to sea-water in composition. Now, as we saw in describing evolution, animal life first inhabited the sea, and it was only after millions of years of struggle that dry land was conquered. When the animal changed its surroundings it carried with it a solution identical with the sea-water it was leaving, in which to bathe its cells. This solution was blood plasma. And still, even in man, the tissue cells are bathed in a solution like sea-water—the blood plasma. It is part of the function of the kidney to see that this plasma is kept exactly at the right composition. If too much sodium chloride is taken, therefore, it is excreted : if too little, sodium chloride disappears from urine.

Sulphates and phosphates are other important salts in the urine. The former come from protein foods some of which contain sulphur. Phosphates we have already seen, are necessary in the form of calcium phosphate, in the building of bone. Calcium, however, is excreted mostly by the colon. This may take phosphates with it so that this salt is excreted from the body by both routes. Sodium, potassium, and magnesium are also present in the urine in small quantities. varying with the amounts present in the diet.

HOW UREA IS EXTRACTED FROM THE BLOOD

Besides these substances, the urine also contains organic compounds which are derived from the proteins, fats and carbohydrates of the diet. Those derived from the protein foods contain nitrogen. The most important of these is urea. This substance we have already seen, is formed by the liver from the excess amino-acids in the blood. From the liver it flows round the circulation, until it comes to the kidney which clears the blood of all its contained urea. About thirty grams pass out of the body daily. If urine is allowed to stand and be acted upon by bacteria containing a special ferment, the urea is split up into ammonia, producing an "ammoniacal" smell. That curious plant the soya bean contains this special ferment and is used, therefore, to estimate the urea in urine.

Urea, as we have seen, may come from amino-acids derived from food, or from those resulting from the wear and tear of tissue cells. This being so, the urea in the urine casts a strong light on the processes of waste and building up in the tissues, particularly when the amount of protein food taken is known.

Uric acid—derived from the nuclei either of cells in the food, or the tissues of the body, is another constant organic constituent of the urine. This substance may form a pinkish deposit in concentrated acid urine. The amount in the blood and urine therefore casts light on what changes are occurring in nuclear substances.

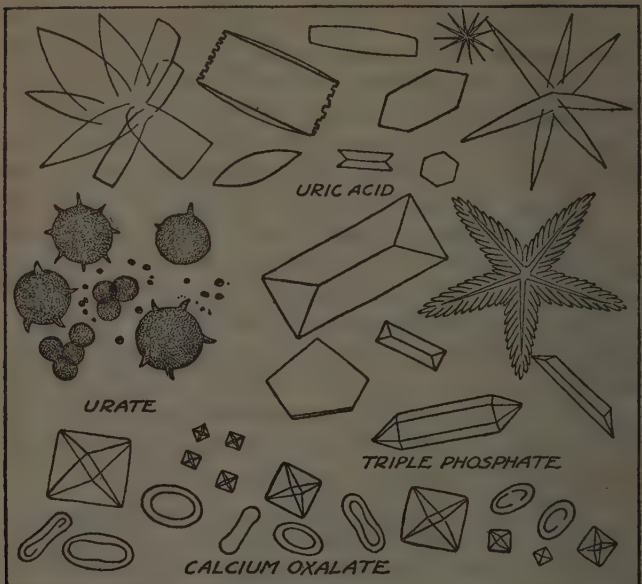


Fig. 1. *Typical crystals in normal urine.*

We have seen how in gout the uric acid is increased in the blood. Beyond a certain amount the blood cannot dissolve it, so that suddenly crystals are deposited in the joints (particularly the big-toe joint) which becomes hot, red and swollen. This is an "attack of gout." Amino-acids also find their way in small amounts into the urine with the substance creatinine, and this, as we have already noted, gives us a hint as to the amount of muscle we have used up.

The yellow colour of the urine is due to a pigment, *urochrome*. This pigment is probably made from the bile. We have seen that this may be re-absorbed from the gut, and carried back to the liver. Some of this re-absorbed bile, which, you remember, is really two sorts of pigments, is carried over into the blood, and so to the urine. Some urochrome, however, may also come from the green colouring matter of plants—*chlorophyll*.

Before describing the structure of the kidneys it is of interest to notice not only what substances are present in the urine, but also what are not. The kidney is presented with blood which, as we have seen, consists of cells and plasma. This plasma has albumen and

globulin (proteins) in it, as well as sugar and bile pigments. It is surely remarkable that none of these appear in the urine in health. When they do we know that either the kidney is diseased or something is radically wrong with the tissues in their use of these substances.

It can be readily appreciated how important urine is, in telling us facts about the chemistry of the human body, both in health and in disease. Finally, examination of urinary sediment under the microscope gives more information, for by this means cells, crystals and bacteria can be seen. Fig. 1 shows typical crystals found in the urine.

We must next ask how the urine, this fluid derived from the blood which enters the kidney, is excreted. In this connection it is important to remember that all the substances in the urine are formed in various tissues of the body, whence they enter the blood. The kidney's function is to rid the blood of these substances which, if they accumulated, would poison it. If both the kidneys are taken out, then these poisons accumulate. In some diseases the kidneys are virtually destroyed so that this unfortunate event does occur, with the result that the body is poisoned. This particular mode of poisoning is called *uræmia* (pron.: yoo-ree'm-ia).

The work of the kidney, therefore, is to preserve the normal composition of the blood. It excretes any new substance entering the blood, and meets and counteracts any change in it.

To understand how the kidney performs these tasks, we must first describe its structure in some further detail. If a kidney is cut along its middle, as in Fig. 2, it is seen to consist of a slightly streaked outer part, known as the cortex. Inside this are several blunt-pointed portions, which are all directed towards a collecting cavity or basin. These blunted portions form the medulla of the kidney, and the space to which they point is called the pelvis.

The pelvis forms a bag, collecting the urine; it empties by a pipe at one side—the *ureter* (pron.: yoo-ree't-ter). Running close to the ureter is the renal artery which, as we have already seen, comes straight off the large main artery in the abdomen—the aorta. The renal artery, which is very large considering

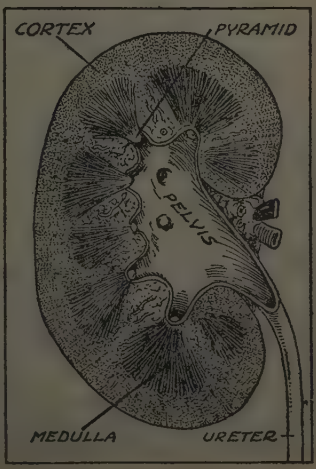


Fig. 2. Section of a kidney.

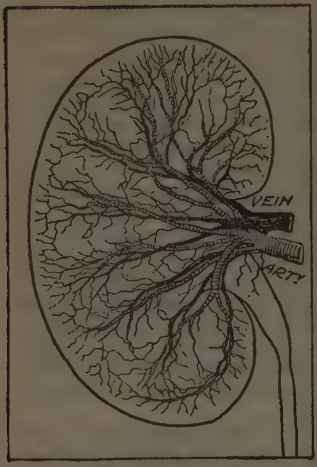


Fig. 3. *The blood vessels of the kidney.*

the size of the organ it is supplying, enters the kidney beside the pelvis. Here it divides into branches which radiate fanwise, each branch passing between blunted portions known as pyramids. This is clearly shown in Fig. 3.

Under the microscope the kidney seems rather a complex structure (Fig. 4). Most of its substance is composed of small tubes, or *tubules* (pron.: tu'be-yools), whose job it is to convey urine down to the collecting bag or pelvis. Each of these tubules is connected at one end with a little tuft of blood vessels, wrapped in a bag of very thin cells. This is known as a *glomerulus* (pron.: glomm'-er-ulus), and is the most important part of the kidney. For the glomerulus, as you see in Fig. 5, opens into the end of the tubule, into which it actually secrets the urine.

Blood enters the glomerulus along one small artery. Whilst it passes through the intricate maze of capillaries which form the tuft, it loses water and other substances which constitute urine. Eventually, another small blood vessel leaves the glomerulus. Its blood

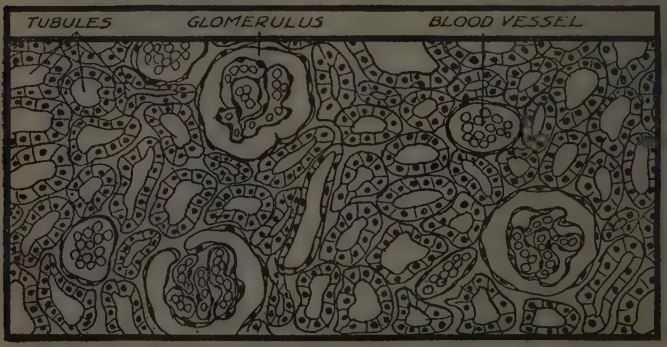


Fig. 4. *A section of kidney under the microscope.*

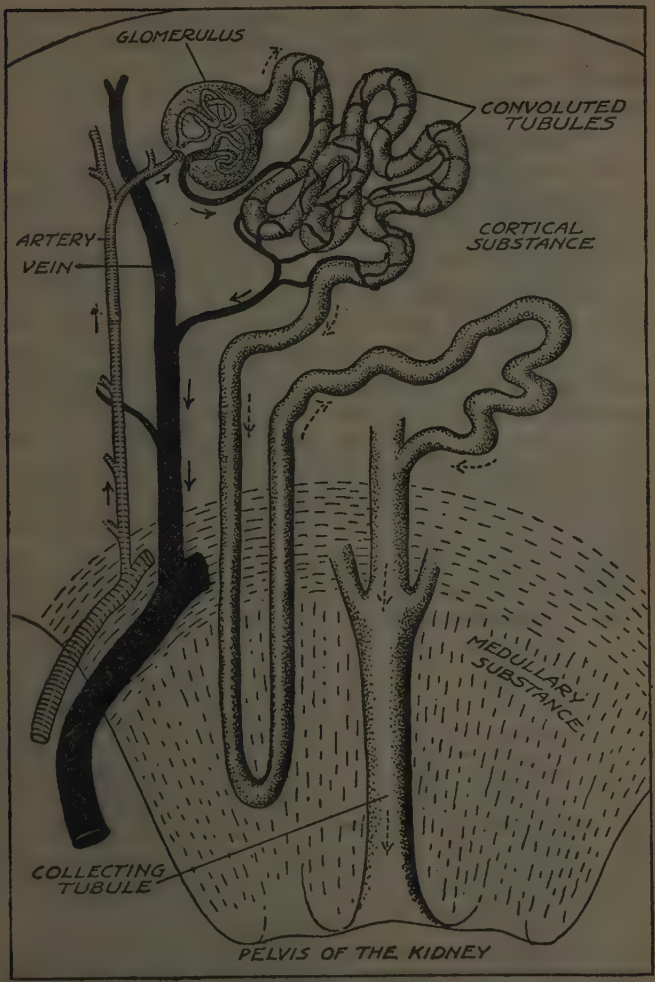


Fig. 5. How urine is secreted—its passage from the blood to the pelvis of the kidney.

content has now been cleaned of all harmful substances. From the diagram you will see that this vessel now goes on to supply the tubules with blood, finally forming small veins which collect together and join with others to form the renal vein. This runs alongside the renal artery back to the main inferior vena cava.

THE ESSENTIAL PARTS OF THE KIDNEY

The essential parts of the kidney then, are the glomerulus and the tubule. The tubule itself runs a surprisingly erratic course. First it dips down, as you see in Fig. 5, into the medulla, after which it doubles on its tracks and comes back almost to its starting point. Finally it joins a straighter, larger tube called a collecting tubule, which opens into the pelvis of the kidney. This complicated course has never yet been adequately explained. It is known that the different loops of the tubule have different functions, because the cells in them are different—but what these are we do not know.

Under the microscope the cells of the kidney can be seen, and those over the tuft of the glomerulus are very flat and thin. This enables urine to be filtered through easily. The twists of the tubules, however, are lined with thicker cells which have small hairs on them, though these are too small to be seen in our figure.

It will be appreciated that each glomerulus and tubule together form a minute organ capable of excreting urine; this organ is called a *nephron* (pron.: neff'-ron). Of these nephrons there are more than four million in each kidney.

When the kidney is doing its daily work, only a small number of these nephrons are used, the remainder form a reserve. For this reason, a large number of kidney nephrons can be destroyed without causing harm to the body. In fact, not only can one kidney be completely removed without harm, but a fair fraction of the other as well. In such a case all the remaining nephrons will have to work full time to keep the body free from poison—but they can do it. The kidney forms a beautiful example of how liberal Nature is in the provision of organs vital to the more efficient functioning of the human body.

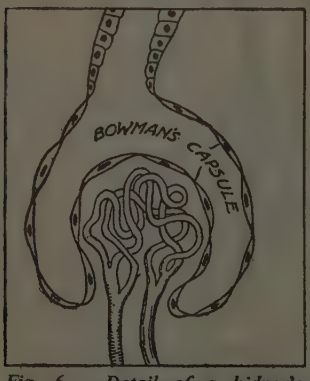


Fig. 6. Detail of a kidney's glomerulus.

These facts about the structure of the kidney were discovered by Bowman in a general way as long ago as 1842, but precisely how

each nephron works in the formation of urine is still disputed.

First of all, let us consider the glomeruli. As we have seen, these consist of small coils of blood capillaries, contained in a very thin bag of thin, flat cells. Blood flows into these capillaries, and some of it filters through the outer bag into a space at the top of the tubule, known as Bowman's capsule (Fig. 6).

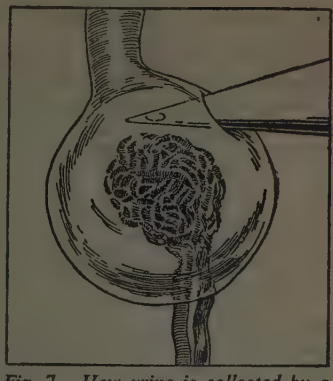


Fig. 7. How urine is collected by a needle from the Bowman's capsule in kidneys.

For many years it was not known what happens to blood inside this tuft of capillaries. Recently, however, with the aid of a microscope, a minute needle has been stuck into the capsule as it is secreting, as shown in Fig. 7. By this method fluid has been analysed, and compared with the composition of the blood inside the glomerulus. It is found that it is blood without its protein. Only the large protein molecules of blood are held back. Salts (sodium chloride and others), sugar, and urea are all passed through the capillaries of the glomerulus into the tubules and are not retained.

Two points of interest arise as a result of this important discovery. First, it is clear that protein in the form of albumen does not appear in normal urine—because the glomeruli hold it back. If these delicate structures are injured by disease then albumen may appear. Albumen in the urine is therefore often a sign of kidney disease.

Secondly, it will be noticed that sugar passes through into the Bowman's capsule. But sugar is not present in the normal urine. What happens to it then? In a very ingenious way all the sugar is re-absorbed by the tubules back into the blood. We shall see that this fate overtakes other substances besides sugar.

We mentioned above that the normal person passes about fifty ounces of urine in the day. We can now understand how this amount may be altered. If the pressure of the blood in the little glomerular capillaries is increased, then more urine will filter through. In experiments on kidneys it has been shown that the amount of urine formed, actually does vary with the blood pressure in the artery to the organ. People who have high blood pressure, therefore often pass an increased quantity of urine.

The tubules of the kidney have also very important work to do, for as we have seen, the filtrate that comes from the glomerulus is very

different from the formed urine. What are these changes, and how are they brought about?

Either something can be added to the fluid to alter it, or something taken away—or possibly both these events may occur. Actually it is thought that re-absorption is the most important function of the tubules. Imagine a tubule presented with the fluid from the glomerulus containing urea, glucose (sugar) and various other salts. The tubule now absorbs a lot of the water, so making the solution about seventy times as concentrated. Urea, being a substance which is of no use to the body, it leaves alone. Sugar, however, is of use, so that it is re-absorbed into the blood until a normal level is reached. If there is still more sugar inside the tubule it will not be absorbed, but pass on with the urea into the urine.

The kidney tubules therefore re-absorb water, and certain substances of importance to the body, which are presented to them in what is filtered through the glomerulus. But is there anything more? Can the tubules secrete? Why are the cells of the tubules so different in various regions? These questions received a rather surprising answer when it was shown that certain fishes have kidneys which have no glomeruli. Urine in these animals must be *secreted* by the tubules. But does this occur in man? Again we have reached the borderland of knowledge which research is busy exploring.

HOW BLOOD AND BODY FLUIDS ARE KEPT CONSTANT

Our short review of the working of the kidney provides another example of the way each organ of the body works for the good of the body as a whole—in short, of integration. The great function of the kidney is to keep the composition of the blood and fluid of the tissues constant. This it does by getting rid of all substances which are present in excess, or are in themselves actually harmful. For instance, if the urea of the blood is not excreted, the body becomes poisoned : headache, vomiting and other symptoms develop. This is the condition, already mentioned as uræmia, which occurs in advanced kidney disease.

To perform its function properly, the kidney must be very sensitive to any change in the composition of the blood. And so it is. For instance, if the blood contains one hundred and seventy milligrams of sugar per cent, none appears in the urine—as this amount is normal. But if it rises to one hundred and ninety milligrams, then some of the sugar appears in the urine. The kidney is trying to bring down the level in the blood to normal.

A similar rule applies to water in the blood. If an excess is drunk, then the kidney excretes it—but after a certain delay, not at once. Probably in this matter the kidney is controlled by endocrine secretion from the pituitary gland. In certain people where part of this gland is lacking, enormous quantities of urine are passed,

even though the victim is tortured by thirst. If such a person is given an extract of pituitary gland, the amount of urine becomes normal. This evidently means that the kidney is in intimate relation in its working with the pituitary gland. It is more evidence of the way all parts of the body are dependent on one another, and how impossible it is to study each organ in isolation. For may we not guess that other endocrine glands and nerves act upon the kidney, regulating its special excretory function?

THE KIDNEY'S GREAT RESERVES

Another interesting fact about the kidney is the way it helps to preserve the right degree of alkalinity in the blood. We have already seen how important this is in Chapter VI, and how certain salts in the blood, such as carbonates and phosphates, act as " buffers," preventing much change in reaction. The lungs also, as we mentioned in Chapter VII, play an important part. Finally, the kidneys ensure this important stability. If the blood tends to become acid, the kidney secretes alkaline ammonia which neutralizes the acidity. If the blood leans towards alkalinity, then the ammonia from the kidney disappears. Lungs, blood, and kidneys—three entirely different factors—combine to perform one function, the keeping of a stable reaction of the blood. It is another beautiful example of integration.

In normal life, not all the kidney nephrons are at work. Always some are working whilst others are resting, like workmen on their various " shifts." In consequence the reserve of the kidney is very large. Of the nine million nephrons present in both kidneys together, about seven millions may be removed, and yet the amount of urine secreted remains unchanged. This of course means that the remaining two millions are " doing overtime " in the interests of the body. And since the fluid must travel more quickly along the tubules, in order to keep up the volume of urine, concentration is weakened. The urine in this case is pale and dilute. This failure to concentrate urine is therefore an important sign of kidney failure.

THE EFFECT OF DIURETICS

Any drug given for the purpose of increasing the amount of urine passed, is called a *diuretic*. Such a drug can act in two main ways. Either it can cause the glomeruli to secrete more urine, or stop the tubules absorbing the normal amount of water.

If one takes a large dose of urea, then this substance is increased in the blood and, after excretion by the glomeruli, in the kidney tubules too. Here it attracts water, preventing its re-absorption, with the result that the quantity of urine passed is increased.

Coffee contains a substance called *caffein*. This substance is responsible both for the mental stimulation and the desire to pass water, which result from taking strong coffee. The latter effect is

due to the caffein opening up all the glomeruli, which are normally resting—so that both shifts of working nephrons are busy at the same time, with a resulting great increase in the amount of work done—in this case the quantity of urine secreted.

We have seen how the kidney forms the urine. We must now follow this fluid from the kidney until it leaves the body.

Fig. 2 shows the blunt pyramids of the kidney through which the urine is poured into a large collecting bag, the kidney pelvis. From

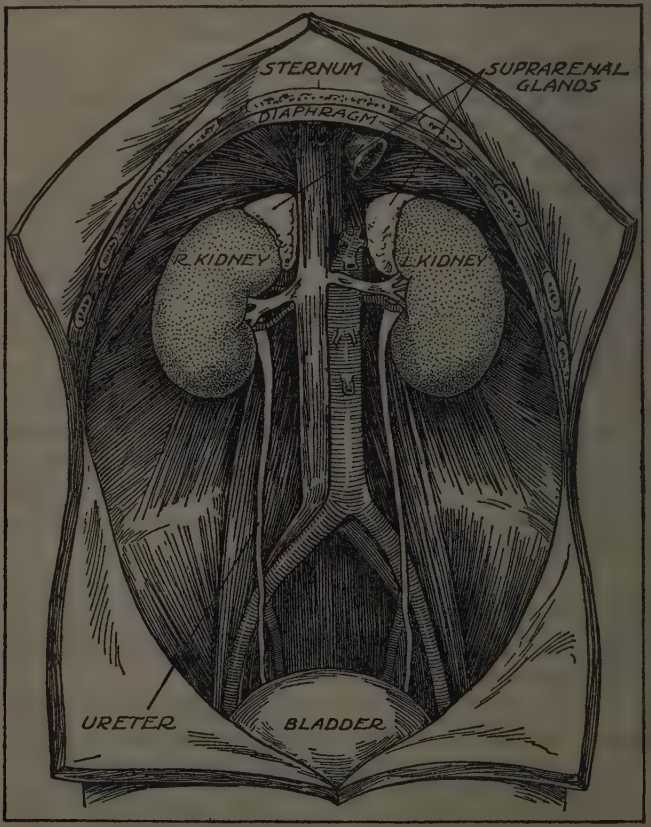


Fig. 8. The kidneys as they lie in the body.

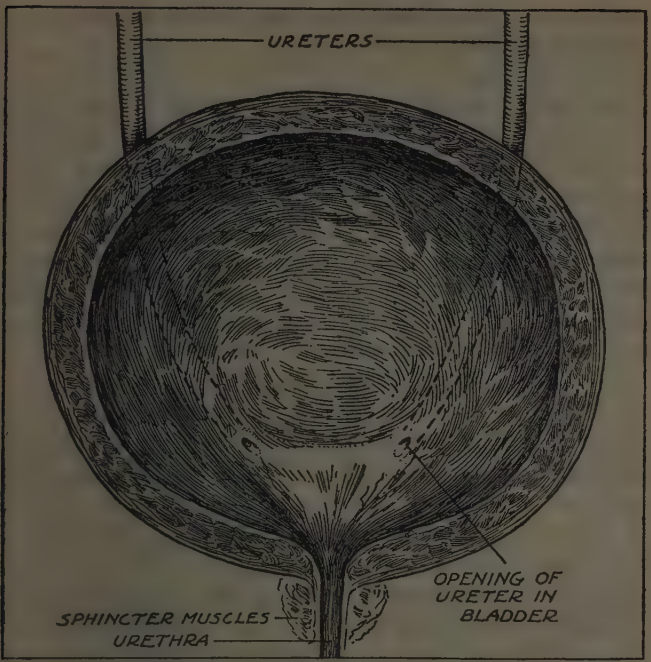


Fig. 9. A cross section of the bladder showing the two ureters opening into it.

here the urine runs down a long muscular tube, the ureter, which ends in the *bladder*. This course is shown in Fig. 8.

The bladder is a useful collecting cistern, into which urine is continually draining via the two ureters, which open into it (Fig. 9). When it gets full the desire to pass water is produced.

The bladder is a muscular bag, the wall of which is lined by layers of cells. The muscle is arranged for the most part circularly, so that when it contracts it squeezes out the contents of the bag. Some fibres, which run from the narrow neck of the sack to the top, have a particularly powerful action in expelling urine. Around the neck of the bladder is a sphincter muscle. This muscle is essential to prevent leakage of urine. If it fails to work, then the urine cannot be held and drains away continuously. Part of this sphincter can be controlled by the will, so that one can voluntarily stop the desire

to pass water. The bladder is plentifully supplied with nerves from the bottom of the spinal cord.

Let us now see how this muscular bag plays its part in holding and excreting urine.

Suppose first that the bladder is quite empty. Drop by drop urine falls into it through the openings of the two ureters. As this urine collects it gradually distends the containing bag. As it does so rhythmic waves of contraction flow over the muscular wall. These shallow waves become stronger as the fluid within accumulates. They send up impulses to the spinal cord, as a result of which a remarkable thing happens. The tone of the bladder muscle diminishes, the bag gets bigger, and the waves become smaller again. Still the urine accumulates, and it is not long before the process repeats itself. But this cannot go on indefinitely, and soon these impulses penetrate into the cord and up to the brain, where one becomes aware of them as a desire to pass water.

HOW THE MIND CONTROLS THE BLADDER

Usually this desire is answered by the act of ridding the bladder of its contents. But not always. Perhaps the occasion is not convenient. In this case the brain sends down impulses which result in further dilatation of the bladder, and again the pressure from within is eased, and for a while the desire to pass water disappears. We have all performed this little experiment on ourselves at some time or another. Finally, however, the need becomes urgent. Then the mechanism of passing urine comes into play. The muscle of the bladder wall contracts, squeezing on the urine within, whilst at the same time the sphincter muscles round the neck, which have been so important in holding the urine back, now relax. The urine now passes out—pushed not only by bladder contraction, but by contraction of the muscles of the abdomen, and even by the diaphragm above. Notice how one sometimes takes a deep breath before passing water—this means that the diaphragm is descending to increase the pressure inside the abdomen, which in its turn acts upon the bladder aiding it in pushing out its contents. The urine now passes along another muscular tube (Fig. 9), the *urethra* (to be distinguished from the ureter), to the outside. At last the waste products of the tissue laboratories have been cast out of the body.

You will notice how important in daily life is the control of the bladder by the higher centres in the brain. In babies this control does not exist. As the accumulating urine causes distension of the bladder, impulses pass up to the spinal cord, and back again along the motor nerves to the bladder muscle, so that urine is released as a simple reflex, the baby being quite unconscious of the act. Training babies (or domestic animals for that matter), consists of developing the power of inhibiting or stopping this inborn reflex.

Another point that is brought out in our description of the stages of the act of passsing urine, is of just the opposite kind. To commence the act, the brain must release the reflex from its inhibition. In nervous people, particularly hysterical women, this release cannot be managed, so that for a day, or even two days, the victim, though in considerable pain and discomfort cannot pass any water. In such people a hot bath, or even the sound of running water exerts a strange liberating effect, and often achieves the desired result.

Temperature in fact has a strong relation to passing urine. This arises first from the fact that the cooler it is the less one sweats, and therefore the more fluid must be excreted by the kidneys. Also every one has noticed how passing from a warm room to sudden cold outside, frequently produces a desire to pass water. This is a reflex from the nerve endings on the skin, which have been stimulated by the cold air. A sudden change to heat has a similar effect. Both a hot and a cold bath tend to produce a desire to pass water.

The simple act of passing water is performed perhaps three or four times a day. Like so many familiar daily acts, it arouses a minimum of interest. This short description of the formation of the urine, its storage and final expulsion has perhaps revealed facts sufficiently wonderful in themselves to rouse admiration. But the riddles still to be solved are many, and no doubt the story as finally worked out will be even more remarkable.

CHAPTER XIII

THE INFLUENCE OF THE GLANDS

In the previous chapters we have described some of the complicated chemical changes which go to form the total metabolism of the body. These changes are sufficiently complex in themselves. How are they all controlled so that one group fits in with another to the ultimate benefit of the body as a whole?

Of recent years—indeed mostly in the twentieth century—discoveries have been made of chemical substances which circulate throughout the body controlling these processes of metabolism. Sometimes they stimulate, sometimes they inhibit. Always they keep the body's chemical changes in order, so that they do not interfere with one another. These chemical regulators are built up in factories scattered through the body, called *endocrine glands*.

Perhaps the best example of an endocrine gland and its secretion or hormone, is in the pancreas. We have already described this organ playing its part in digestion by secreting juices into the intestine like an ordinary gland. But inside the pancreas are the islets of Langerhans which really form by themselves quite another

organ with a different job to perform. These small islets form together an endocrine gland, for they secrete into the blood their product insulin, which circulates round to various organs, in particular the muscles and the liver, controlling their use of sugar.

By a network of hormones of this kind the various processes of metabolism are governed. Now growth is the result of successful chemical change by which organs add to their bulk. Especially does this apply to bones. It depends therefore very closely on body metabolism—and thus on the hormones which control it. Reproduction of young is the logical result in nature of growth. So sex and reproduction come under the sway of hormones too. Many activities of mind and body depend upon a smooth chemical change for their performance. We have seen, for instance, how good and bad temper may depend on changes in the blood sugar.

It will be seen that nearly all the activities of the body are influenced by hormones. The body is integrated, made to act as a unit by these substances. In fact chemical integration was the original method adopted by animal bodies. It was only later that evolution evolved the more delicate and efficient nervous system. And in spite of this, the primitive chemical method remains vital.

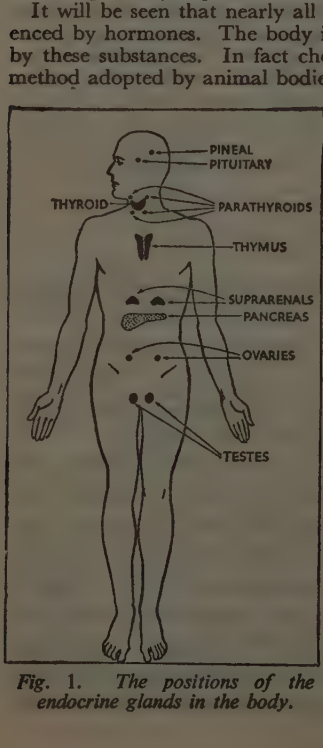


Fig. 1. The positions of the endocrine glands in the body.

In order to avoid confusion, it must be noted here that other organs besides the endocrine glands can secrete hormones. The first hormone discovered, —secretin—comes from the duodenum. Perhaps the factor formed in the stomach which enables bone marrow to build healthy blood cells should be called a hormone.

The endocrine glands are scattered over the body as in Fig. 1. Here you see the *pituitary* and *pineal* glands in the skull, the *thyroid* and *parathyroids* in the neck, and below, the *thymus*.

In the abdomen are the two *suprarenal* glands, which lie like a couple of small " cocked hats " on top of the kidneys. The endocrine is in the islets of Langerhans. In the female at each side of the womb are *ovaries*.

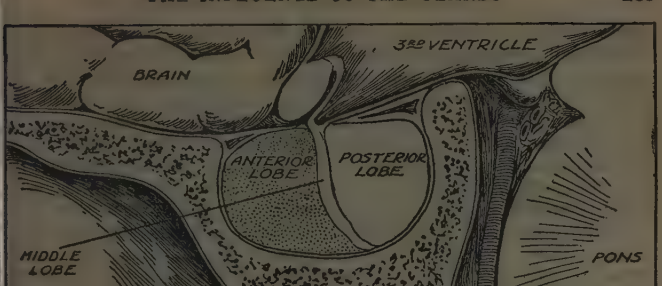


Fig. 2. The pituitary gland, showing its three lobes in position inside the skull.

In men the two *testicles* or *testes* migrate into the *scrotum*. These sex glands, called *gonads*, secrete the sex hormone.

The most important of all these glands is the pituitary inside the skull. This gland, discovered by anatomists long ago, was thought to be responsible for the watery (pituitary) secretion from the nose, and so got its name. Its structure is shown in Fig. 2. Here you see that it is made of three main parts—anterior, middle, and posterior lobes. Indeed it is not one gland but a colony of three. This is a peculiar fact which we shall notice again—that often what was originally thought to be one gland has on further research been found to consist of two or more quite different parts.

The three parts which make up the pituitary lie in a snug hollow of bone, shaped like an old-fashioned Turkish saddle. The gland is, therefore, surrounded on all sides by bone except at the top where it is covered by a tough membrane, through which a hollow stalk runs, joining the pituitary to the base of the brain. Through this stalk secretion is thought to enter the third brain ventricle.

What is the action of the secretions formed by these parts of the gland? Before we answer this question it must be emphasized that the pituitary gland, by its hormones, influences every other endocrine gland in the body. It has been aptly described, therefore, as "the leader of the glandular orchestra." This function it performs by producing many different hormones.

The anterior lobe secretes a hormone that stimulates growth. In childhood this "growth" hormone is chiefly responsible for the changes in size, from infancy to adolescence. If there is too much hormone being formed at this time then the child grows too rapidly and becomes a giant. Pictures of these giants appear from time to time in the daily newspapers. In the museum of the

Royal College of Surgeons, London, is a skeleton of an Irishman O'Brien, who was seven feet seven inches tall. John Hunter, the pioneer surgeon, who founded the museum kept watch on O'Brien for years before he died in order to study afterwards the reason for his gigantic size. And there in the skull of this man is an enormous hole of bone where the pituitary gland was lodged. The gland itself must have been very large to fill this space, and almost certainly was the cause of O'Brien being a giant. How near Hunter came in his insatiable curiosity to a great discovery made a century later!

Giants, contrary to general belief are often not very strong people. Perhaps they "outgrow their strength." For the secretion which comes in excess from the anterior lobe of the pituitary, becomes in many cases exhausted later on, and the giant becomes a weak though large man. Often giants die early. For this reason they are often not as good as might be expected at athletic sports.

If, as sometimes happens in disease, the secretion of growth hormone increases suddenly after adult life has been reached, there a condition known as *acromegaly* (pron.: a'kro-meg-al-y) results. This is a tragic complaint which alters the whole appearance of the sufferer. A delicate handsome woman develops a coarse skin, large nose, thick lips, and huge hands.

WHY SOME PEOPLE ARE FAT

Just as too much growth hormone produces giants, too little makes dwarfs, but there are many varieties of response to lack of the growth hormone. Sometimes Peter Pans are formed—people who remain children, perfectly proportioned, but with the minds and bodies of children all their lives. Sometimes premature ageing occurs, and a girl of nine years becomes as wrinkled and haggard as a woman of eighty. Perhaps the commonest form of deficiency has been portrayed in the "fat boy" of *Pickwick Papers* by Charles Dickens. Fat and sleepy, always yawning, this comic boy is a typical case of pituitary disease.

Besides producing this important growth hormone, the anterior part of the pituitary produces hormones which control the sex glands, the suprarenals, thyroid and parathyroid, as well as the islets of Langerhans in the pancreas. On these endocrine glands the pituitary "plays the tune." The storage and disposal of fat and carbohydrate is also under the influence of the pituitary. Some people lose fat in one part of the body and increase it in another. The pituitary governs this change, but how we do not know.

The various kinds of unusual growth, giants and dwarfs, etc. can be very conveniently studied at fairs and circuses. Here the dwarfs are not the beautiful Peter Pan type, but another where the bones of the legs and arms stop growing owing to the epiphyses closing too early. (We saw how important they are in Chapter III.

In these people, the trunk and head may develop normally, for which reason they have long bodies and short limbs—not perfectly proportioned parts as in the Peter Pans. These short-limbed people are often very intelligent and so are very suited for performing in a circus "turn." It is still doubtful how much the pituitary is responsible for their peculiar growth.

The posterior lobe of the pituitary produces two or three different hormones which affect the womb, and the blood pressure. The first is responsible for the contraction of the muscles of the womb in child-birth, which causes the "labour pains." The second causes a rise of blood pressure—but how much it is responsible for permanent high blood pressure is not clear. When we described the formation of urine we mentioned the relation of a third hormone to the volume of urine passed. When this part of the pituitary is diseased, the urine may increase in amount enormously. By injecting the patient with posterior pituitary this may be stopped.

The middle lobe of the pituitary has had no particular function allotted to it, but it surrounds the central tube which leads up to the brain, and it seems very probable that its secretion passes along this channel into the cerebro-spinal fluid in spaces in the brain.

The thyroid gland lies across the windpipe in the neck, below the voice-box (Fig. 3). It weighs less than an ounce, and can often be seen in thin people.

Under the microscope (Fig. 4) are seen spaces containing cloudy secretion surrounded by secreting cells. These spaces are for the storage of secretion. As soon as the demand increases the stored supply disappears. It is passed into the blood, and so to the organs of the body that need it. If the thyroid gland is enlarged, it is known as a *goitre*.

The thyroid has particular use for iodine. A large part of the iodine taken in the diet finds its way to this gland where it is built up into the internal secretion, called *thyroxine* (pron.: thi'-rok-seen). Over this substance research has had one of its greatest successes. For not only has it been chemically analysed, so that its exact

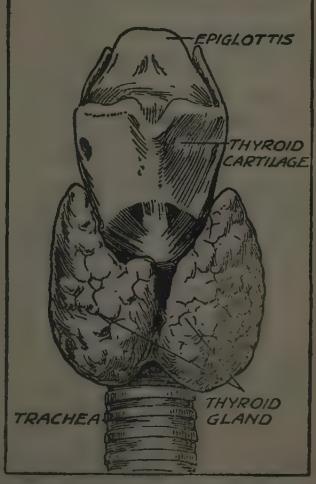


Fig. 3. The thyroid gland from in front.

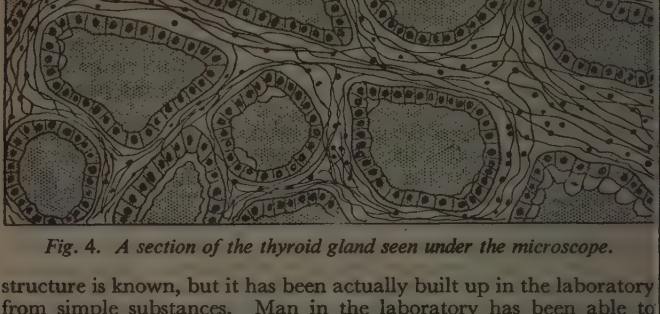


Fig. 4. *A section of the thyroid gland seen under the microscope.*

structure is known, but it has been actually built up in the laboratory from simple substances. Man in the laboratory has been able to imitate the work of the thyroid. Thyroxine acts on many tissues of the body, but most dramatically on the muscles. The more thyroxine the faster the body burns, the higher becomes its metabolic rate, and fat rapidly disappears. With shortage of thyroxine the body and mind become sluggish, and fat increases.

WHAT IS A CRETIN?

These activities of thyroxine are illustrated in disturbances of growth almost as startling as in the case of the pituitary. If thyroid is deficient in infancy then a *cretin* results. Growth ceases both in mind and body. The tongue protrudes from the mouth, the belly becomes protuberant. Such a child is a pathetic, almost disgusting sight. But it can all be changed by giving it a small tablet of thyroid a day. Soon the fat disappears and the child plays like any other.

If the deficiency in thyroxine develops in adult life, then the failure mentally and physically can be watched. Such a person becomes slow witted and heavy, with a monotonous voice, and increasing weight. The skin becomes coarse, pads of fat form in the neck, above the collar-bones particularly. The complexion becomes a sallow yellow often with a bright pink spot on each cheek. The hair falls out, and the heart beats sluggishly in tune with the rest of the body. These peoples' fires are burning low. Life smoulders, and all the glitter and sparkle of the healthy body becomes a dull, smoky image of its true self. But again a small tablet containing thyroid substance can turn such a person back to lively health.

As we have already seen, the thyroid needs iodine to build up the secretion, thyroxine, which has such a dramatic effect upon the body. What happens if there is a shortage of iodine in the diet? Iodine is present in sea-water, and in animals and plants which inhabit the sea. The farther one goes from the sea, the less iodine is there in the soil. It happens, therefore, that in mountainous

country far from the sea there is frequently a shortage of iodine. This means that the thyroid glands of people in these regions have to attempt the task of "building bricks without straw." The result is that the gland works very hard at its hopeless problem, thereby enlarging. This increase in size is one form of goitre, and in Derbyshire is known as "Derbyshire neck." Such goitres can be prevented by adding small quantities of iodine to the diet.

Just as there can be too much pituitary secretion in the body, giving rise to gigantic growth, so there can be too much thyroid secretion, the results of which are just the opposite. The effects of this are known as Graves's disease—named after a famous Dublin physician who described the symptoms in 1835 for the first time. In this trouble the eyes start out of the head, the thyroid gland enlarges (forming another kind of goitre), the heart beats very rapidly, and there is marked wasting—symptoms just opposite to those of thyroid deficiency. Removal of nearly all the thyroid gland by operation brings the sufferer back to normal.

Embedded in the back of the thyroid gland are four small glands called the parathyroids, two on each side (Fig. 5). It is peculiar that they should lie in such close proximity to the thyroid, for their secretion has, so far as is known, no relationship to that of the thyroid. If these glands are removed, then the calcium in the blood falls lower and lower. Now calcium has a sedative effect on muscle. If it disappears from the blood then the muscles become excitable and "jumpy," so that they twitch, and finally the body goes into a spasm known as *tetany*. This is what happens when the parathyroid glands are removed.

The internal secretion of these glands is called *parathormone*, a substance which, like thyroxine, can be prepared commercially. If an excess of it is injected the calcium in the blood becomes too high, and the muscles sluggish. This calcium comes from the bones. Sometimes, when there is a tumour of the parathyroid glands the bones are robbed of their calcium and bend quite easily.

The thymus (Fig. 6) we mentioned as a gland of mystery still.

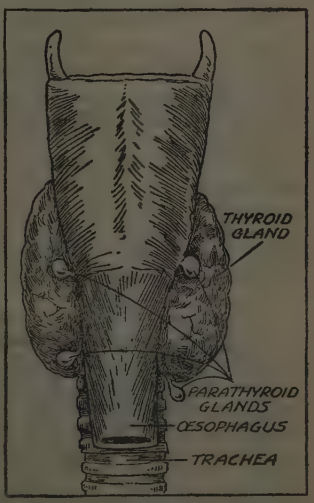


Fig. 5. The four parathyroid glands lodged behind the thyroid.

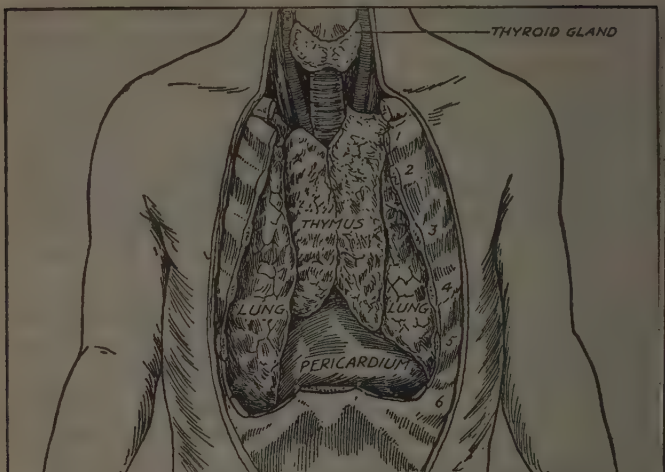


Fig. 6. The thyroid gland and thymus as seen in a two-year-old child.

It has a peculiar part to play in man's life. Situated behind the upper part of the breast-bone, at birth it weighs about a quarter of an ounce, but increases in size rapidly in young children, attaining its maximum size at about the age of five. At puberty it becomes smaller, and by adult life it has practically disappeared.

This curious waxing and waning of the gland gives, perhaps the best clue as to its function. It appears to be an antagonist of the sexual glands, whether male or female. For as they develop, it declines. This withering of the thymus is absent when the sexual glands are deficient or removed. Children with enlarged thymus glands are often small and pale, with delicate skins.

The actual secretion of the thymus has never been isolated and it is even doubted by some authorities if there is one.

The suprarenal glands, which lie on top of the kidneys (Fig. 7) consist of two quite distinct parts, the cortex and medulla. Each of these parts produces a different secretion. To all intents and purposes, therefore, they are separate endocrine glands. Why are they placed in such close relationship to one another? This peculiar neighbourliness of the glands of internal secretion is, as we have noted, a peculiar trick of Nature's, which has so far baffled inquiry.

In this particular case, the two parts, cortex and medulla, come from completely different tissues in the embryo. Whereas the cortex, or outer layer, is derived from a primitive mass of cells

from which kidney and gonads developed, the medulla, or inner part, comes from another group which went on to develop into the nervous system. Yet these two incongruous bed-fellows lie snugly together in the fatty tissue on top of the kidney. This, however, is not so in all animals. In fishes the two parts of the suprarenal are separate—the cortex and medulla form different organs. Some animals have extra suprarenal glands in parts of the abdomen.

GLANDS THAT ARE VITAL TO LIFE

The cortex of the suprarenal is yellow. It contains a large quantity of the fatty substances, *lecithin* and cholesterol, and also strangely enough, vitamin C. The cortex enlarges during pregnancy, though what its relation is to this process is not clear. That it is intimately related to sex is shown when there is cortical overgrowth, as in a tumour. Here there is sudden sex development in young children —so that a young boy, four years of age, may develop hair on his face and body and he may even be capable of sexual intercourse.

A peculiar feature of these overgrowths of suprarenal cortex is that the changes are always towards maleness. If they occur in young girls, these too develop male characteristics of hair and voice, etc. If in grown men, then there is merely accentuation of normal male characteristics. Fortunately, this kind of overgrowth is rare.

In most animals, if the cortex is cut out, death ensues. This applies to man probably, so the suprarenal cortex is vital to life.

In 1855, Dr. Addison, a physician in London, founded the whole study of the endocrine glands in a small book, in which he described cases of people becoming very dark-skinned and weak, and eventually dying, in whom the suprarenal glands were found to be diseased. He therefore said that these glands were essential to life. It was an epoch-making statement, that two such small and unimportant-looking structures should be essential to life. Even now we cannot account for all the symptoms of this Addison's disease.

From this start the functions of other odd, unknown bits of tissue were explored. And so the thyroid and the pituitary, and others began to reveal their secrets.

The suprarenal cortex has of recent years been found to have a controlling power on the sodium in the blood, which disappears from the body when the gland is diseased. Even our table salt (sodium chloride) is becoming linked up then with these recently

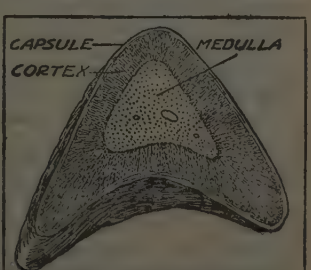


Fig. 7. A cross section of the suprarenal gland.

discovered glands. Carbohydrates and fat metabolism are also thought to be affected in some way by the suprarenal cortex.

The medulla of the suprarenal gland lies inside the cortex. As we have mentioned already, it is derived from the same parent cells as the sympathetic nervous system. And it is intimately related with this system in its action, for it is the factory for the substance adrenalin. This chemical compound is another endocrine secretion which has yielded all its secrets to the researches of the biochemist. It can be prepared in the laboratory with ease. Its correct chemical name is ortho-dioxyphenol-ethanol-methylamine — perhaps the simplest of the names given to the endocrine secretions.

In Chapter VIII we mentioned how adrenalin acts on the endings of the sympathetic nerves of the body, stimulating them. The suprarenal medulla itself, however, is stimulated by the sympathetic nerves. The splanchnic nerves (shown in Fig. 8, page 127), pierce the diaphragm and supply some branches to the suprarenal glands. When these nerves are stimulated the suprarenal medulla liberates adrenalin into the blood stream, where it circulates, coming into contact with the various organs which it stimulates.

WHY A MADMAN IS SO STRONG

Let us note its action a little more fully. Adrenalin is an extremely powerful self-made drug. One thousandth of a grain has an effect on an average man. This action consists of arousing sympathetic stimulation throughout the body. The main things that happen, therefore, after an injection of adrenalin are as follows: a rise of blood pressure, emptying of the liver of its glycogen store for the muscles to use up if the need arises; dilatation of the pupil—even the hair may stand on end as in great terror. Soon the skin pales, the heart beats more rapidly and strongly; the airway is kept clear for the intake of air by relaxation of the muscles of the small air passages, the bronchioles and the muscles of the gut relax, except the sphincters which arrest the process of digestion.

All these are sympathetic effects; all of them are designed to prepare the animal for fighting, for activity—at the expense of the " building-up " activities of the vagus.

Adrenalin is liberated normally in the body, under the influence of great emotion. It is in fact a link between our feelings and our cells. We have all heard of the exceptional strength of a lunatic. This is due to his extreme emotional derangement liberating unusually large amounts of adrenalin, so giving him the " strength of ten " and making several sane men necessary to control him since they have less adrenalin in their blood.

The chemistry of the emotions, however, is difficult, for the fact exists that you cannot create rage or any other emotion in a man by injecting adrenalin. This is perhaps fortunate, for it would

rather complicate matters if a free fight followed each injection.

The internal secretions of the sex glands we shall describe in the next chapter. That of the pancreas, insulin, we have mentioned.

THE MYSTERY GLAND

We should give perhaps a special, though small place to the pineal gland. It is still doubtful whether this gland manufactures an endocrine secretion or not. It is an interesting organ, however, for it is a remnant of a third eye, which was present in the simplest of our vertebrate ancestors. Still in some reptiles traces of this third eye remain. It is not such nonsense then, to talk of having "eyes at the back of your head." You almost have one.

If it has an internal secretion, the pineal must exert an influence very similar to that of the thymus for it tends to shrink at the same time, that is about the age of puberty, when the sex glands are developing. But increase of pineal secretion is said to lead to excessive sexual development a condition similar in some ways to overgrowth of the suprarenal. This unexpected event is evidence of the ignorance that exists as to the real function of the pineal.

Fig. 8 illustrates one of the most important facts about these endocrine glands—their interaction with one another. The intersecting lines indicate the extreme complexity which exists. If there are still problems concerning the functions of each individual gland and its secretion, how much more difficult are those concerning the intricate relationships between one gland and another. At present the subject of their relationships is shrouded in the thick mists of ignorance and few firm facts can be advanced as reliable.

HOW THE PITUITARY INFLUENCES OTHER GLANDS

As we have mentioned, the most important endocrine gland of all is the pituitary. This gland, from its various parts secretes hormones which influence every other endocrine gland in the body. Consequently, when it is diseased symptoms arise, not only from the lack of pituitary hormones themselves, but from disturbance of those of other glands as well. Again, disturbances of other glands may upset the pituitary as well. At once you can see how difficult it may be in a woman showing male characteristics for example, to decide which gland is at the root of the trouble.

A hormone from the pituitary stimulates the thyroid to do more work. If the thyroid is deficient, then the pituitary is found to enlarge. If there is too much thyroid the pituitary becomes smaller.

The pituitary secretes hormones which act on the gonads (ovaries or testicles), and also on the suprarenal cortex. This latter relationship is shown in a remarkable manner by the fact that a tumour of the suprarenal cortex and of the pituitary produce exactly the same results—accentuation of male characteristics in women.

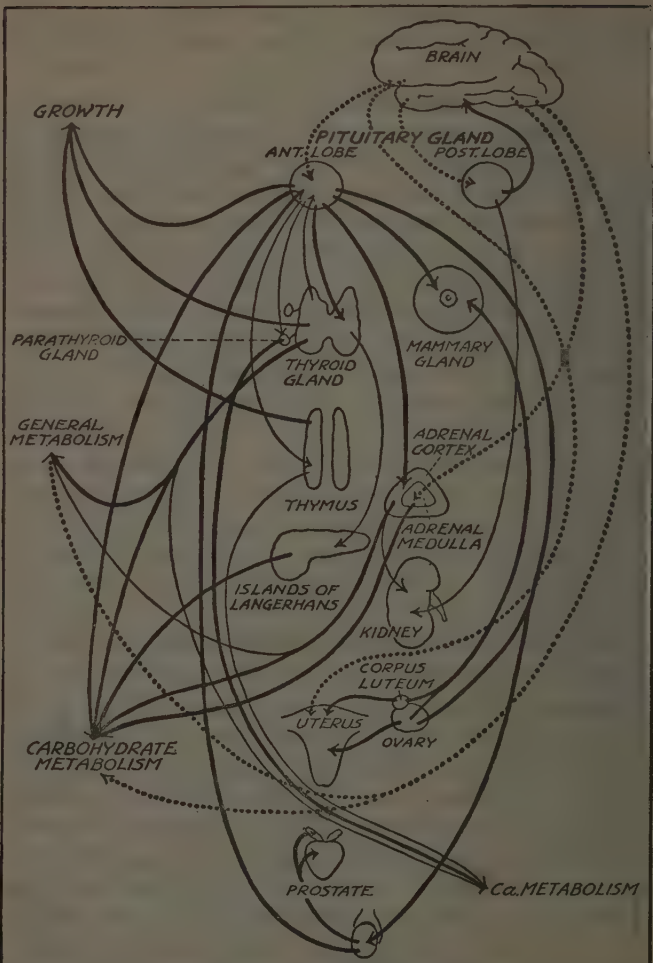


Fig. 8. Diagram showing in simplified form the complex relationships of the endocrine glands to one another.

The pituitary secretes also a hormone which antagonizes the insulin formed in the pancreas. Does it control this vital secretion? Does it cause diabetes?

These examples are sufficient to show how complicated are these relationships, and how difficult they are to work out.

HOW THE GLANDS KEEP THE BODY NORMAL

Of recent years a new idea has been brought forward, suggesting that not only are hormones present in the blood stream, but substances called *anti-* (against) hormones as well. These, as their name implies, act against the hormones, neutralizing their action in much the same way as an antitoxin neutralizes a toxin (poison). This particularly applies at present to the thyroid hormone—thyroxin, and also to the hormone from the pituitary gland which stimulates the thyroid. The way this has been worked out is interesting.

It has been found that if thyroid is added to water in which tadpoles are kept, they rapidly turn into frogs long before their usual time. By this method frogs as small as a thumbnail may be produced. If blood as well as thyroid is added to the water, this remarkable change does not occur. Therefore, it is argued, the blood must contain anti-thyroid hormone. This experiment is neat, but conclusions drawn from it must be viewed with great suspicion.

If these anti-hormones exist where do they come from? Perhaps we have found a function for those glands of mystery, the pineal and the thymus—but we must not rush into this speculation.

Let us end our description by noting that the delicate intertwining of the endocrine glands has one object, and one only—the efficient integration of the metabolism of the body as a whole. In health they all regulate their influences so that a person appears normal in both physique and character.

THE EFFECT OF GLANDS ON CHARACTER

But where does health end, and disease start? We are all made up on different endocrine patterns. The tall, lean fanatic has a very different balance of endocrine secretions from the red-faced, bald-headed, cheerful business man. But neither is unhealthy. They are healthy variations. You will find people whose build and character indicate a large thyroid element in their hormone make-up. Nervous, highly-strung people, thin, with a liking for cold weather, active and inclined to worry, hands that tremble, sensitiveness and perhaps irritability—these are the characteristics of healthy thyroid people. But if the thyroid gland breaks the bounds of activity and secretes its hormone, paying no heed to the calls of the other endocrine glands, or of the body as a whole, then disease is present.

Mood—cheerfulness and melancholy—we have seen is dependent to a large degree on the endocrine secretions. Within certain bounds

optimists and pessimists are normal beings. But when optimism goes to the extent of gaily spending more money than you have got, or pessimism to committing suicide, then behaviour is abnormal.

It has recently been suggested that a woman's greatest capacity for work is during the few days following her menstrual period. During this time the sex-hormone, *œstrin* (pron.: ees-trin), is at its lowest level in the blood. Even our everyday actions and moods, therefore, may be reflected in the hormone changes in the blood.

It may even be that the temperamental differences between human races are due to endocrine balance. The stolid sentimental Teuton, and the logical Frenchman—how do their endocrines differ?

If we could but find an answer it would perhaps be possible by the aid of altering the endocrine balance to lessen international hatreds and quarrels. If only we could find a peace endocrine!

CHAPTER XIV

REPRODUCTION AND SEX

In Chapter I we saw how sex originated. Two small cells married or conjugated—almost all their substance passing into the resulting offspring. We also saw how, in spite of the fact that it meant a reduction in numbers (for two cells produced only one of the next generation) sex paid because it introduced variation.

As evolution unfolded its plan the body became divided into two parts—the one concerned with sex and reproduction, the other with self-preservation. Of these two the sexual is the more important.

Perhaps the real wonder of the human body lies in the fact that it is the best of all armours so far invented for the protection of the sex cells. All the subtleties we have described, of muscle and bone, all the nervous and chemical integration, would be utterly meaningless if there were no sex cells. For it would all endure but for a generation—and then pass into oblivion. The body, then, is but an elaborate casket, bearing its precious burden of sex cells.

In most animals these sex cells are of two kinds—male (sperm) and female (ovum or egg cell). The sperm of man consists of a cell shaped rather like a tadpole, as you see in Fig. 1. The front end is composed almost entirely of nuclear material, which will fuse with the egg cell. The tail, as in the tadpole, is for swimming onwards in the fluid of the womb, until it reaches the female ovum.

The ovum (Fig. 2), has no tail, and does not move actively. It is larger than the sperm as it contains a certain amount of reserve food on which the young fertilized cell will feed at first. It is curious to reflect that even in the actual sex cell it is the male which courts and wins, whilst the female is wooed and won—characteristic persisting in all sexual activities of animals, however highly evolved.

The actual union of male and female sex cell is called fertilization. But before this happens the chromosomes (the coloured rods inside the nucleus) halve themselves in each male and female sex cell. When they unite, therefore, each providing half the normal number of chromosomes, they together produce the normal number for the animal. In the human this number is forty-eight—each sex cell containing, therefore, twenty-four chromosomes. Why it should be forty-eight—no more and no less—no one can say. The cells of the ox, the onion, and the guinea pig, also contain forty-eight chromosomes, so this number is by no means a human prerogative.

In the sexual act (*coitus*) millions of spermatozoa are ejected. Of these but "one small Noah" will survive and find its way to the ovum—attracted by chemical substances. Rapidly, this vigorous sperm cell swims towards its passive goal. As they come into contact the two cells, male and female, fuse. The tail of the sperm cell, now useless, withers and falls off. The female ovum, as soon as it has been fertilized, develops a tough membrane around itself so that no further sperm cells can enter. The nuclei of the two cells now approach one another, and their chromatin mixes. Rapidly now this fertilized cell, or *zygote*, divides into two, each new cell containing partly male and partly female chromosomes. Two, four, eight, sixteen—and so on—it does not take long before the offspring is composed of thousands of cells, lying in the mother's womb.

Curiously enough, it is not absolutely necessary, in some animals

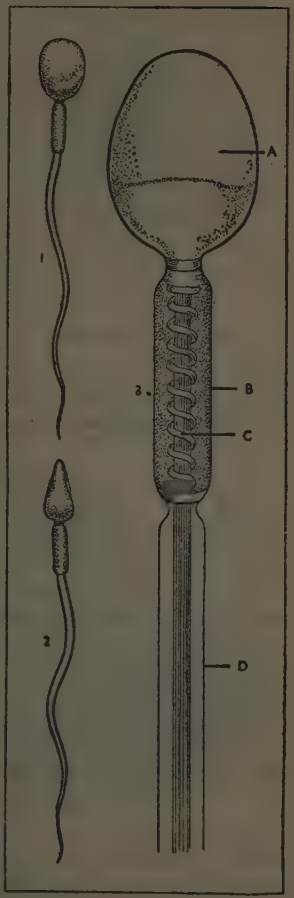


Fig. 1. *A spermatozoon, the male sex cell.* (1) *Front view.* (2) *Side view.* (3) *Detail:* (a) *Head.* (b) *Body, or connecting piece.* (c) *Spiral thread.* (d) *Tail.*

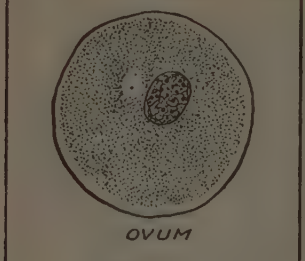


Fig. 2. *Comparative sizes of an ovum and a spermatozoon* (*both enlarged* 150 *times*).

at least, for a sperm cell to be present to set the ovum dividing. Loeb, in 1900, actually succeeded in producing sea-urchins and frogs by pricking, or otherwise stimulating the egg cells of these animals —but the little frogs produced were sexless.

The new being created by this fusion of the parent cells is composed of their very substance. It contains their chromosomes in equal parts. These are the basis of heredity. The sex of this new individual depends on whether " it " contains the sex chromosome or not. This is a chance of heredity. We saw what laws governed sex heredity when we described the bleeding disease hæmophilia. Sex, therefore, depends on the nature of the chromosomes in the successful sperm cell.

As the fertilized zygote divides, each part remains capable of developing into two complete human beings. If these two new cells get separated, they may lodge in the womb, side by side, and develop eventually into " identical twins." For such cells will have *exactly* the same chromosome content, and will, therefore, always be of the same sex, and of very similar characteristics. But twins may also be formed by two separate ova being fertilized independently. The resulting children will, therefore, be related only as much as any brother and sister.

As the fertilized zygote develops it becomes the *embryo*. We saw in Chapter I how this embryo passes through a recapitulation of all the stages of evolution, until it arrives at its ordained design which we recognize in the form of a human baby at birth.

THE CHILD BECOMES ADULT

The baby now passes through infancy and childhood, during which the body grows to adult height and strength. But for twelve to fourteen years the sex glands produce no sex cells, no sperm or ova. At puberty, however, a great change takes place. Boys and girls are transformed into men and women, and this for the most part by the chemical feats of the almost magical endocrine factories. Hair grows in the arm-pits and around the sexual organs. In boys the voice " breaks." Sexual desire develops in both sexes, and the breasts develop in the female with the commencement of *menstruation*.

Menstruation is a process peculiar to man and apes amongst the mammals. Essentially it consists of casting out of the body an unused ovum. Once a month an ovum is produced by the ovary. The womb prepares to lodge this if fertilized. If not, then the lining of the womb with the wasted ovum are cast out.

The female reproductive organs consist of two small egg-shaped bodies, the ovaries, which lie on each side of the pelvis (Fig. 3). Wrapping round each are finger-like processes which lead into a tube (the *Fallopian tube*) which leads in its turn into the top corner of the womb or *uterus*. The neck of the uterus communicates with a tube, the *vagina*, which opens on the surface of the body. The ovary contains some 70,000 cells capable of developing into complete ova or egg-cells. These are all present at birth. None develop properly, however, until puberty.

The ripe ovum develops inside a little bag of fluid which forms a kind of blister on the surface of the ovary. This blister bursts, shedding the ovum into the grasping fingers of the Fallopian tube which guides the ovum into the uterus. Somewhere on its journey down the tube an active sperm cell may fertilize the ovum. In this case, when it reaches the prepared lining of the womb it embeds

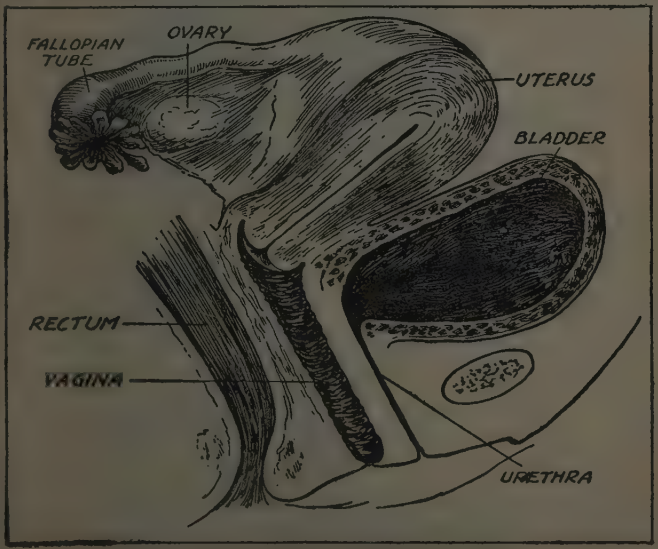


Fig. 3. *Cross section of the female genitalia.*

itself and develops. Pregnancy has commenced. If no sperm cell fertilizes it, it passes out of the body with the next menstrual period.

The male sexual organ is the testicle (Fig. 4). This consists of masses of coiled tubules, all of which collect to run into the *epididymis* (pron.: epy-did-im-mis). This forms a complicated coil lying at the back of the testis, containing in its small bulk some twenty feet of tubule. From here a single muscular tube, the *vas deferens* follows a complicated course, through the groin and pelvis, until it meets its fellow of the opposite side in the substance of the *prostate* gland at the neck of the bladder. Here it opens into the urethra, so that both sperm and urine flow along the same path.

Each sex has in its reproductive organs, vestiges of the opposite sex. And in the prostate gland where each vas deferens joins the urethra there is a little pocket, the uterus of the male. The prostate is a sex gland whose secretion is mixed with the seminal fluid, whereby the sperm cells are roused to greater vigour and activity. The

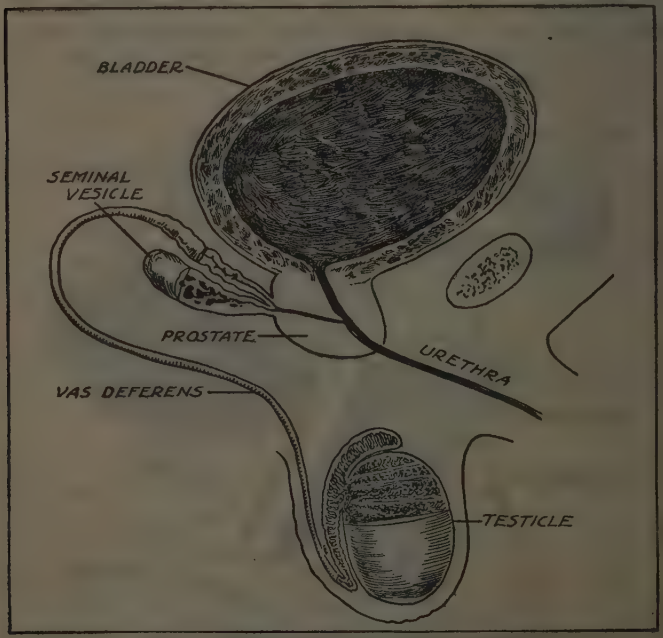


Fig. 4. Cross section of the male genitalia.

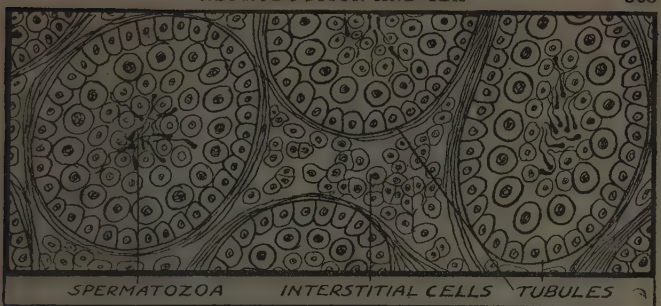


Fig. 5. Microscopic section of a testicle (enlarged 150 times) showing how spermatozoa are formed.

urethra passes through the tubular *penis*, an organ especially adapted to the function of introducing the seminal fluid into the vagina. This is achieved through special erectile tissue consisting of a network of spongy spaces which when filled with blood become tense and hard, so erecting the organ. From birth until puberty no sperm cells are formed in the testis. At puberty this commences.

We have seen how the sexual cells are produced, but this is only one part of the function of the sex glands. They also produce endocrine secretions. It is these substances which flow into the blood stream, so reaching the uttermost parts of the body. They are responsible for the development of hair, voice, etc., or what are known as secondary sexual characteristics.

THE CYCLE OF SEX

In a microscopic section of a testis (Fig. 5) groups of cells will be seen lying between the tubules of the organ. These interstitial cells secrete the hormone known as *testosterone* (pron.: test-t'os-ter-oan). Curiously enough, this hormone is very similar to the female sex hormone called œstrin. This testosterone is constantly formed in man throughout all the length of active sexual life, and is passed out of the body in the urine. It is not produced if the anterior lobe of the pituitary gland is removed. Perhaps the strangest part of all is that the male urine contains the female hormone œstrin.

The ovary's endocrine secretion is, as we have seen, œstrin. In many female animals sexual activity is found to go in cycles. For instance, bitches are sexually active only twice a year, whilst in mares it is more frequent. This period of being "on heat" is called *œstrus* (pron.: e'es-trus). During it the ovum is shed from the ovary and lies ready to receive the male sperm cell, and become fertilized. If the ovaries are removed this œstrus cycle, as it is called,

ceases. It also disappears during pregnancy. The ovaries ar responsible, therefore, for the changes, by producing a female se hormone (œstrin). In human beings no obvious cycle exists.

But what governs this periodic production of œstrin? Again th anterior part of the pituitary gland takes the stage. This leadin gland it seems, not only initiates the changes which bring on puberty in both sexes, but governs the formation of œstrin in the ovary If injected into female mice this particular pituitary hormon produces an enormous number of ripe ova. This forms the bas of a very valuable test for pregnancy. For the urine of pregnan women contains a large quantity of this anterior pituitary hormone If, therefore, this is injected into mice it soon causes their ovarie to be studded with broken blisters or follicles.

When the ovum is shed from the ovary it leaves behind it a ra place in which special yellow or *lutein* (pron.: loo'-teen) cells develop These form the "yellow body" which produces another set hormones whose design is to preserve the life of the new bein formed from the fertilized ovum—in short, to preserve pregnancy for Nature assumes that every shed ovum will be fertilized

NATURE PREPARES FOR FERTILIZATION

In human beings the hormone œstrin seems to be partly responsibl for building up the special lining to the womb, so preparing it fo the ovum which is expected to lodge there. If this ovum is no fertilized, then it is a cast out with the lining of the womb (menstrua tion), and the œstrin in the bloo drops to a low level. But if th ovum is fertilized, then the cel of the yellow body which fill th scar whence the ovum has com show great activity in producing new hormone *progesterone* (pron pro'g-ester-oan) which perform several functions. First it sees th no more ova are shed. This pr vents the possibility of a secon fertilization while the first embry still occupies the womb. Then th lining of the womb is furth adapted to harbouring the embry which becomes firmly lodged, an any tendency to abortion miscarriage is overcome. It al is largely responsible for the d velopment of the *mammary* glan so that the mother is ready

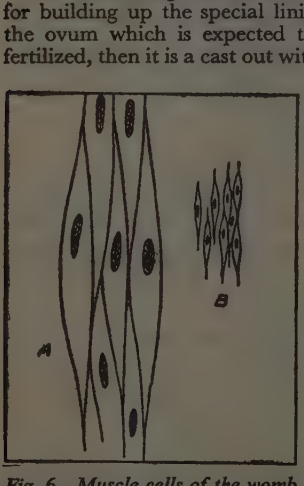


Fig. 6. Muscle cells of the womb. (a) *In pregnancy.* (b) *In a virgin uterus.*

feed her child when it is born.

If the ovum is fertilized, then pregnancy ensues. A woman is most fertile about ten days after menstruation, and least fertile during the week before this event. This is due to the fact that the ovum is usually shed from the ovary, and commences its journey down the Fallopian tube to the womb, about this time.

Pregnancy in humans lasts nine months. During this time the uterus increases from its virginal capacity of about two teaspoonfuls of fluid to about ten pints. This amazing increase is achieved by the muscle cells of the walls of the womb growing enormously (as you can see in Fig. 6) perhaps to as much as ten times their normal size. While this is going on, the lining or mucous membrane of the womb also changes, becoming spongy and filled with blood.

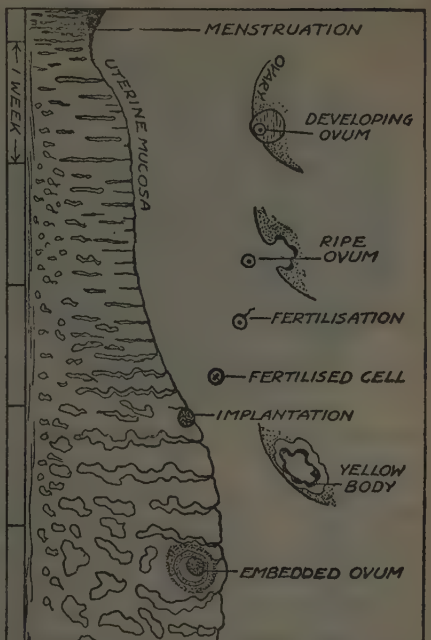


Fig. 7. The beginning of pregnancy. How the uterus and ovary prepare for the implantation of the fertilized ovum.

As the fertilized ovum comes into contact with the uterine mucous membrane, it eats its way in until soon it lies quite buried in the uterine wall as you see in Fig. 7. Gradually, the embryo in its wrappings grows, until it fills the whole cavity of the womb, and one side only invades the uterine wall. This portion eventually forms the *placenta* (pron.: pla-s'en-ta) or "after-birth" (Fig. 8). Through it for about six months the blood of the mother comes into intimate contact with that of her child, and food is passed from the one to the other. It is during the stage when the placenta is forming that the young embryo is least securely attached to the

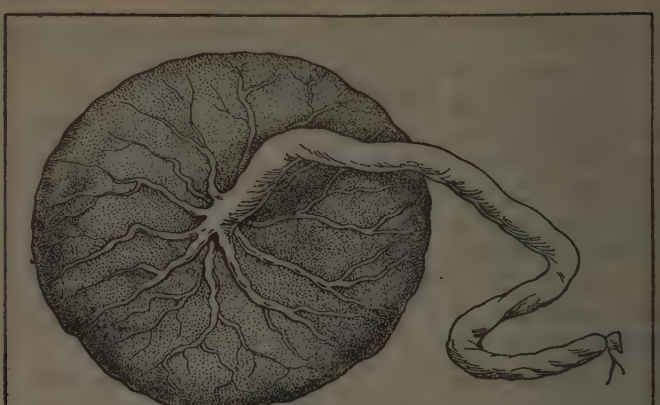


Fig. 8. *The placenta and the umbilical cord.*

wall of the womb. This occurs about the third month of pregnancy, and is the most likely time for dislodging of the embryo.

The embryo itself is developing all the while. The outer layers of cells invade and attach it to the uterine wall. Between this outermost layer and the embryo itself there develops a cushion of fluid which prevents it from being injured as it is moved about (Fig. 9). This fluid forms the "waters" which come away first at birth. For a little while the embryo is nourished from the yolk-sac, which contains the yolk of the human egg and serves for a time the same purpose as the yolk of a hen's egg. But soon this supply is exhausted, and nourishment is obtained from the mother's blood in the placenta. For this purpose the circulation in the growing embryo or fœtus is very different from that in the child after birth. The *umbilical* cord which enters the fœtus at the *navel* carries blood between fœtus and placenta. Special cavities exist in the heart of the fœtus so that the blood shall not have to pass through the lungs. The fœtus in the womb, therefore, lives without breathing.

Within a few minutes of birth the whole of this circulation is changed. The first breath taken opens up the blood vessels of the lungs so that blood now flows through them, as in the adult. Within a week the umbilical cord drops off, leaving the scar at the navel as a last reminder to us of life within the womb.

At the end of nine months the fœtus is ready to be expelled from its comfortable retreat into the light of day. The uterus has, for some time, been suffering small rhythmic contractions—now they

become more powerful, until the "pains of labour" set in.

The actual onset of labour is probably governed by the endocrine secretion of the posterior part of the pituitary gland. This finally overcomes opposite influences from the progesterone and placental hormone, and produces the rhythmic, painful contractions of labour. As the muscle of the uterus contracts pushing the fœtus down, the neck of the bag, or cervix, is drawn up and widened so as to permit of the passage of the infant inside its bag of water. Soon this bag bursts, its contained "water" flows away, and the infant is expelled followed in a few minutes by the after-birth or placenta.

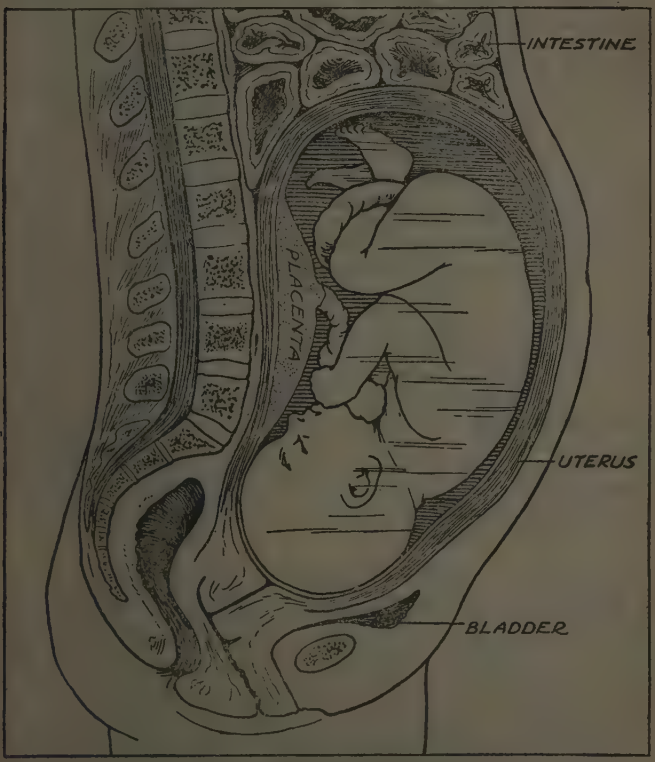


Fig. 9. The fœtus in the womb.

Within a few days after this the uterus has shrunk down again to a fraction of its size at full term. This it does partly by virtue of firm contraction of the muscles, making the uterus immediately after birth feel as hard as a cricket ball. This contraction stops any serious bleeding and restores the uterus to its normal size.

HOW HUMAN MILK IS PRODUCED

The next, and final stage of reproduction is *lactation* (pron. lak-tayshun) or the production of milk. During the whole of pregnancy the mammary glands have been gradually enlarging. At birth they are almost ready—but not quite—for their task. For it is not until two or three days after birth that a flow of milk comes. For this to occur the stimulus of a suckling infant is almost an essential. If the infant is put regularly to the breast, milk continues plentiful for about nine months. If this is not done the milk disappears, and the child has been robbed of its best start in life.

We have already seen how the preparation of the breasts depends on the progesterone. At birth, however, the "yellow body" of the ovary, having served its purpose, disappears. With it goes any inhibition of the actual secretion of milk, which therefore soon commences to flow. But the pituitary gland again takes a part and also adds a hormone which stimulates the secreting mammary gland to do its work. Regular emptying of the breast by the suckling infant continues to excite the process of secretion. Not only does it achieve this, but the act of suckling has been found to be accompanied by further contraction of the empty uterus during the first week or so after child-birth. The infant is therefore by this act not only doing good to itself but also to its mother.

Sex then, is Nature's method of attaining to reproduction. And reproduction is her idea of immortality—and not only immortality. For if each couple of mated human beings produce three children then not only have they immortalized their own bodies, but they have added new life to the world. From Nature's point of view it is a perfectly satisfactory arrangement to kill off the parents when they have passed their fruitful age.

WHAT IS GROWING OLD?

But Man as a social animal thinks otherwise. There are some lives which human society thinks valuable quite apart from the reproductive point of view. And most people are convinced that the world would be a better place if they themselves could live longer in it. So the search for rejuvenation has gone on. Voronoff and Steinach are the names most associated with it. Both have approached the problem from the point of view of the sex glands.

It will, perhaps, lend clarity to our ideas of rejuvenation if, for a moment, we consider what "growing old" really means. We

begin to die from the day we are born, in the same way as a fire begins to burn itself out from the moment it is lit. We remain alive only by virtue of the harmony which exists between these various remarkable structures—the organs of the human body.

In this book we have tried to describe these organs, and the way their functions interweave like threads producing that exquisite tapestry which is a human life. This process, this integration, is however, imperfect. And the measure of its imperfection is expressed in the time of death. If the imperfection is great at birth, as it sometimes is in, for example, a badly made heart, then life is cut off right at the beginning. However perfect all the other organs, to a defect in one the whole body is sacrificed. Usually, however, it takes about seventy years for the defect to show itself. During this time different organs wear out at different rates. In some people the brain goes first, in others the heart, or the kidneys, and so on, until the failing organ falls out of stride with its companions, and death of the body as a whole ensues.

When a man with a brilliant, active brain, dies from the failure of his heart or lungs, then the tragedy of death seems most bitter. The most vivid examples are those of Mozart or Keats, cut off at the powerful zenith of their arts, by failure of their bodily integration.

For disease is only a rapid local ageing and death, which occurs in particular circumstances. The perfectly integrated body resists disease as part of its daily task.

ATTEMPTS TO FIND THE SECRET OF YOUTH

Rejuvenation then must mean repairing all the defects in the various organs as they occur, so keeping the balance of all. But the human body judged even as a machine, is far more complex than any machine ever conceived by man, and those defects are not easily detected.

Perhaps one of the most striking points about old age, is the decline of the sexual glands. For this reason Voronoff transplants testes of young apes into men, and Stenach follows similar lines.

If the testes of a man are the only part of his body growing old then this method is admirable. But if his brain cells are atrophied or his heart is waning, then to introduce an active young testicle into the declining body, strains integration and may even shatter it.

Let us leave this description of the human body with the realization that it is as near perfection as anything yet created. During the time which it is on this earth of ours let us use it worthily.

Each humble one of us can then peacefully rest to the end of his days contemplating those words which so truly describe the wonderful story of the human body:—

"We are such stuff as dreams are made on; and
our little life is rounded with a sleep."

A

ABDOMEN. Belly.

ACCOMMODATION (eye of focus). Focusing the eye on a near object.

ACETABULUM (pron.: as-see-t'abulum). The cup in which the top of the femur or thigh-bone articulates.

ACETYL CHOLINE (pron.: as-e'e-til koa'-leen). A chemical liberated at the ends of the vagus nerve.

ACROMEGALY (pron. akro-m'egally). Enlargement of hands and face.

ADDUCTORS (MUSCLES). A group of muscles which run on the inner side of the thigh.

ADRENALIN (pron.: a-dr'een-alin). The internal secretion of the suprarenal glands.

AFFERENT (SYSTEM OF NERVES) (pron.: a'ffer-ent). Nerves concerned with conveying impulses towards the brain.

AGAR (pron.: a'y-gar). A fluid which sets on cooling: used for preparing bacteria.

AGGLUTINATION (pron.: ag-gl'oot-y-n'aysh-on). Clumping in the blood.

AGGLUTINOGENS (pron.: ag-gl'oo't-y-jo-jens). Substances which are clumped or agglutinated.

ALBUMEN (albumin) (pron.: alb-y'oom-en). A common protein found in blood and egg-white, etc.

ALVEOLI (pron.: al-vy'-oaly). The small air sacs of the lung.

AMBOCEPTOR (pron.: am-bo-s'ep-tor). An antibody which has two arms one linking with "complement," the other with the invading body.

AMINO-ACIDS (pron.: a-me'eno-acids). The simplest breakdown products of proteins.

AMPHIBIANS (pron.: amf'ibians). Animals which live on land or in water.

AMPULLA (pron.: am-po'ol-a). Swelling.

AMYLASE (pron.: amy-l'ase). An enzyme which splits starch and sugars.

ANABOLIC (pron.: a-n'ab-ol-ik). Building up processes of metabolism.

ANTHRAX. A disease named after the bacillus of this name.

ANTIBODIES (pron.: an-ti'b-od-ys). Bodies in the blood which neutralize invasion.

ANTI-HORMONES. Substances which act against hormones.

ANTITOXIN (pron.: an-ty-t'ok-sin). An antibody which neutralizes toxin.

ANUS (pron.: a'in-us). The opening of the bowel on the surface.

AORTA (pron.: a-'orta). The main blood vessel of the body, arising from the heart.

AQUEDUCT OF SYLVIUS. Narrow channel between third and fourth ventricles of the brain.

AQUEOUS HUMOUR (pron.: a'yk-wy-us hum-ur). Watery substance in the front chamber of the eye.

ARRECTOR PILI (pron.: a-rrek-tor pilee). Muscles which erect the hairs.

ARTERIOLES (pron.: ar-te'er-i-oals). Small arteries.

ARTHROPODS. Jointed animals, e.g., lobsters.

ARTICULATE (JOINTS). The manner in which two bones join.

ASCENDING COLON. Part of large bowel on right side of body from cæcum to hepatic flexure.

ASPHYXIA (pron.: ass-f'iksy-a). Suffocation.

ASTIGMATISM (pron.: ass-t'ig-matism). An error of the lens of the eye.

ATLAS VERTEBRA. The first cervical vertebra.

AURICLE (pron.: o'r-rickle). A thin-walled chamber of the heart.

AURICULO-VENTRICULAR NODE. A node of conducting tissue lying between auricles and ventricles.

AXILLARY ARTERY (pron.: a'k-sill-ary). Artery that runs across the arm-pit.

AXONS (pron.: a'k-sons). Long process of a nerve cell.

B

BACILLI (pron.: bass'-ill-i). Rod-shaped bacteria.

BACTERIA (pron.: back-t'eer-ia). Microscopic organisms.

BACTERIOPHAGE (pron.: back-t'eer-io-farj). A substance that dissolves bacteria.

BASILAR MEMBRANE (pron.: baz-i-lar m'em-brain). A part of the inner ear on which the organ of Corti rests.

BASOPHILE (pron.: b'az-o-file). Staining with basic dyes, e.g., blue.

Bell Animalcule (pron.: bell anim'-al-kewl). A single-cell animal shaped like a bell.

Biceps Femoris (pron.: bi-s'eps f'emmoris. A muscle at the back of the thigh.

Bilirubin (pron.: billy-r'ubin). An orange bile pigment.

Biliverdin (pron.: billy-v'er-din). A green bile pigment.

Brachial Artery (pron.: br'akeial). Main artery of the arm.

Bronchi (pron.: br'onk-i). Main air tubes of the lung.

Bronchioles (pron.: br'onk-i-oals). Small air tubes.

Buccinator (pron.: b'uk-sin-aytor). A muscle of the cheek.

C

Cæcum (pron.: s'ee-kum). A blind sac, at the beginning of the colon.

Caffein (pron.: k'aff-een). A drug found in coffee.

Calcaneus (pron.: kal-ka'iny-us). Bone of the heel.

Calorie (pron.: k'al-or-y). A unit of heat, i.e., the amount which raises the temperature of 1 c.c. of water 1° C.

Caninus (pron.: kan-i'n-us). A muscle of the face—which in action produces a snarl.

Capillary (pron.: kap-i'll-arry). Smallest blood vessel.

Carbohydrate (pron.: kar-bo-h'idrait). Substance containing carbon and hydrogen and oxygen in the same proportions as water.

Carboxy-hæmoglobin (pron.: karbok-sy hee'm o-glob in). Hæmoglobin combined with carbon monoxide.

Cardiac Impulse. The impulse of the heart felt on the chest wall.

Carotene (pron.: ka'r-ott-een). A pigment contained in carrots and related to vitamin A.

Carotid Arteries (pron.: k'arotid). Arteries of the neck.

Carotid Sinus. A centre of nerves on the internal carotid artery.

Catalyst (pron.: k'att-alist). A substance that greatly increases the rate of a chemical reaction.

Cellulose. A tough, starchy material in plant cells.

Centrosome (pron.: s'en-tro-soam). A body concerned in cell division.

Cerebellum (pron.: serr-y-be'll-um). Part of the brain.

Cerebral Cortex (pron.: s'err-y-bral k'or-teks). Outer layer of the brain.

Cerebrum (pron.: se'rr-y-brum). The main part of the brain.

Cervical Region (pron.: s'erv-ikle). Neck region.

Chlorophyll (pron.: kl'o-ro-fill). Green pigment of plants.

Cholesterol (pron.: ko'al-es-teroll). A fatty substance of the body.

Chordæ Tendinæ (pron.: k'ordat'endinee). Cords attached to the valve flaps in the heart.

Choroid Coat (pron.: ko'-roid). Layer of the eyeball outside the retina.

Choroid Plexus (pron.: k'-roid pl'ek-sus). A network of blood vessels which dip into the ventricles of the brain.

Chromatin (pron.: kr'o-matin). Material which stains in nuclei of cells.

Chromosomes (pron.: kr'o-mosoams). Portions of nuclei into which chromatin is divided.

Chyme (pron.: kime). Soft mass of material.

Cilia (pron.: si'lly-a). Whip-like processes from cells.

Ciliary Muscles (pron.: si'll-y-ary). Muscles of accommodation in the eye.

Clavicle (pron.: kla'vv-ikle). Collar-bone.

Cocci (pron.: ko'ks-i). Round bacteria.

Coccygeal Region (pron.: k'oksy-jeel). Near cocci and on tip of spine.

Coccyx (pron.: k'ok-six). Last bone of the spine.

Cœliac Artery (pron.: se'el-iak). Artery to stomach.

Cochlea (pron.: kok-ly-a). The bony, hearing part of the ear.

Coitus (pron.: ko'y-tus). Sexual intercourse.

Colloid (pron.: kol-loyd). Suspension of microscopic particles in solution.

Collagen (pron.: k'oll-a-jen). Firm substance in fibrous tissue cells.

Cones of the Eye (pron.: koans). Detecting organs for light, in the eye.

CONJUNCTIVA (pron.: kon-junk-ti-va). Membrane lining the lids and front of eyeball.
CORNEA (pron.: kor-n'ee-a). The clear front of eye.
CORONARY ARTERIES (pron.: k'orron-arry). Arteries of the heart muscle itself.
CORPUS CALLOSUM (pron.: k'or-pus kall-o'-sum). Part of the brain above the ventricles.
CORTEX (pron.: k'or-teks). Outer layer.
CREATIN (pron.: kre'e-a-tin). A chemical found in muscle and urine.
CRETIN (pron.: kre'e-tin). Dwarfism due to lack of thyroid gland.
CUTIS VERA (pron.: k'ewtis ve'era). True skin.
CYTOPLASM (pron.: s'i-to-plasm). The part of a cell outside the nucleus.

D

DEFÆCATION (pron.: dee-fe'k-ay-shun). The act of opening the bowels.
DELTOID MUSCLES (pron.: de'l-toyd). Muscle covering the shoulder.
DENDRITES (pron.: d'en-drites). Short processes of a nerve cell.
DESCENDING COLON (pron.: koal-on). Colon on left passing down to rectum.
DIAPHRAGM (pron.: di'-a-framm). Midriff sheet of muscle between thorax and abdomen.
DIASTOLE (di-a'ss-toly). Interval between heart-beats.
DIFFUSION OF GASES. Spread of gas in a still atmosphere.
DIURETIC (pron.: di-ur'-et-ic). A drug which induces increased passage of urine.
DOMINANT (CHARACTERISTICS). Characteristics which appear if present.
DORSALIS PEDIS ARTERY. Artery on back of foot.
DUODENUM (pron.: doo-o-de'en-um). Beginning of small intestine.

E

ECTOPLASM (pron.: e'k-to-plasm). Outer layer of cytoplasm.
EFFERENT SYSTEM (of nerves). Nerves which carry impulses away from brain.
ELECTRO CARDIOGRAM (pron.: el-e'k-tro ka'rd-y-o-gram). Instrument for detecting electrical changes in the beating heart.
EMBRYOLOGY (pron.: emm-bry-'oll-ogy). Study of development of the body from the egg-cell upwards.
EMBRYOS (pron.: e'mm-bry-os). The developing fœtus.
EMETIC (pron.: em-e'-tik). A drug which produces vomiting.
ENDERMIC (pron.: enn-de'rr-mik). Application of a drug via blistering.
ENDOCRINE GLANDS (pron.: endo'k-reen). Glands of internal secretion.
ENDOTHELIUM (pron.: enn-do-th'eel-ium). The living cells of blood vessels.
ENDOPLASM (pron.: enn-do-plasm). Inner part of cytoplasm.
ENZYMES (pron.: e'n-zime). A catalyst made in the body or by living tissues.
EOSIN (pron.: e'-o-sin). An orange dye.
EOSINOPHILE (pron.: ee-o-s'in-o-fil). The property of staining with eosin.
EPIDERMIS (pron.: ep-py-de'rrmis). Outer layer of skin.
EPIGLOTTIS (pron.: ep-py-glo't-tis). Leaf-like structure at top of voice box or larynx.
EPIPHYSES (pron.: ep-pi'ffy-sees). Centres of ossification at ends of bones.
EREPSIN (pron.: er-e'p-sin). An enzyme which splits protein derivatives to amino-acids, found in small intestine.
EUSTACHIAN TUBE (pron.: yoo-st'ay-shy-an). Tube from ear to pharynx.
EXTERNAL AUDITORY MEATUS (pron. me'ay-tus). Tube from outside to ear-drum.

F

FÆCES (pron.: fee'-sees). Excretion from the bowel.
FALLOPIAN TUBE. Tube from ovary to uterus.
FEMORA (pron.: f'em-orra). Thigh bones.
FEMORAL ARTERY (pron.: short e). Artery of the thigh.
FIBRIN (pron.: fi'-brinn). The substance which forms blood-clots.
FIBULA (pron.: fi'bb-ula). Smaller bone of leg.

FIBRINOGEN (pron.: fi-br'in-o-jen). The substance from which fibrin is formed.
FIBROBLASTS (pron.: fi'-bro-blast). Young fibrous tissue cells.
FILTERABLE VIRUS. A virus which passes through special filters.
FISSURE OF ROLANDO. The main fissure on the cerebral cortex, dividing motor from sensory areas.
FLAGELLÆ (pron.: fla'jelly). Whip-like processes of bacteria and protozoa.
FŒTUS (pron.: fee'-tus). Growing embryo in the womb.
FONTANELLES (pron.: fon-tann-e'lls) Gaps between the bones of the infant's skull.
FORAMEN (pron.: for'-ay-menn). A hole.
FORAMEN OF MONRO. The hole between lateral and third ventricles.
FORMIC ACID. An acid found in the stings of ants, and other places.
FOURTH VENTRICLE. The cavity beneath the cerebellum of the brain.
FOVEA CENTRALIS (pron.: fo-v'eea sen-tr'al-is). Keenest visual spot of the retina.
FRONTAL BONES. Bones of the forehead.
FRUCTOSE (pron.: frūk-tose). Fruit sugar.

G

GALACTOSE (pron.: gal-a'k-tose). A sugar.
GALL BLADDER. Bag containing bile, lying beneath the liver.
GAMETE (pron.: ga'm-meet). A sexual cell.
GANGLION (pron.: ga'n-gly-on). A collection of nerve cells.
GASTROCNEMIUS (pron.: gass-tro-ne'em-ius). Muscle of the calf of the leg.
GEL (pron.: jell). Jelly-like state of a colloid.
GENES (pron.: je'ens). Characteristics grouped on chromosomes.
GENITALIA (pron.: jee-ny-ta'ylia). The sexual organs.
GLOBIN (pron.: glo'-bin). A protein which combines with hæmatin to form hæmoglobin.
GLOBULIN. A protein of the blood.
GLOMERULUS of the kidney (pron.: glömm-e'r-ulus). The essential filtering organ of the kidney.
GLOTTIS. Upper end of voice-box.
GLUCOSE (pron.: glu'-kose). The simplest sugar.
GLUTEUS MAXIMUS (pron.: glo'ot-y-us ma'k-simm-us). Muscle of the buttock.
GLYCOGEN (pron.: gli'-ko-jen). The storage form of glucose.
GOITRE (pron.: go'y-ter). Swelling of the thyroid gland.
GONADS (pron.: go'-nads). The testicles or ovaries.

H

HÆMATIN (pron.: he'em-at-in). Iron containing pigment.
HÆMOGLOBIN (pron.: heem-o-glo'b-in). Hæmatin and globin (protein) hæmoglobin of the blood.
HÆMOLYSIS (pron.: heem-o'l-y-sis). Destruction of red blood cells.
HÆMOPHILIA (pron.: heem-mo-f'illy-a). Bleeding disease.
HAVERSIAN CANALS (pron.: havv-e'r-sy-an). Canals in bone through which blood vessels go.
HERBIVORA (pron.: her'b-y-forra). Animals which eat plants only.
HOMO NEANDERTHALENSIS. A type of early man.
HUMERUS (pron.: hew'-merr-us). Main bone of arm.
HYDROCEPHALUS (pron.: hi-dro-k'ef-alus). Water on the brain.
HYDROXYL (pron.: hi-dr'ok-sil). OH —or basic chemical radicle.
HYPODERMIC (pron.: hi-po-de'r-mik). Beneath the skin.
HYPOGASTRIC (ARTERY) (pron.: hi-po-ga'ss-trik). Artery running to umbilicus.
HYPOTHALAMUS (pron.: hi-po-th'al-amm-us). Region of brain below the third ventricle.

I

ICHTHYOSAURUS (pron.: ik-thy-o-sa' urus). An animal of the Devonian period.
IGNEOUS ROCKS. Rocks formed from volcanic action.
ILIAC (ARTERIES) (pron.: il'ly-ak). Arteries running from the aorta to the thigh.
ILIUM (pron.: i'll-y-um). Bones of the hip.

ILIO-PSOAS (MUSCLES) (pron.: i'lly-o so'-ass). Muscles running across the ilium to the thigh-bone.

INCLUSION BODY. A mass formed inside a cell from virus action.

INCUS (pron.: i'n-kus). A bone of the middle ear.

INFERIOR MESENTERIC (ARTERY) (pron.: mes-senn-te'r-ik). Artery from the aorta supplying descending colon.

INFERIOR VENA CAVA (pron.: ve'en-a ka'y-va). Main vein collecting blood from both lower limbs.

INSPIRATION (of breathing) Breathing in.

INSULIN (pron.: i'n-sul-in). The internal secretion of the pancreas.

INTEROSSEI (MUSCLE). Small muscles of the hand.

INTERCOSTAL MUSCLES. Muscles between the ribs.

INVERTASE. An enzyme which acts on sugars in the small intestine.

ION (pron.: i'-on). An electrical particle in solution.

IONIZATION (pron.: i-o'nny-z-aysh-on). The process of putting ions into the tissues.

IRIS (pron.: i'-ris). The curtain which surrounds the pupil of the eye.

ISLETS OF LANGERHANS. The dotted collections of cells which produce insulin.

K

KATABOLIC (pron.: kat-a-b'olik). Breaking down side of metabolism.

KETONE (BODIES). Poisonous, acid bodies formed in the body from fat.

KINÆSTHETIC CAPSULES (pron.: kinees-th'et-ik). Capsules which enable the brain to detect limb movement.

L

LACHRYMAL GLAND (pron.: la'k-rymal). Tear gland.

LACTATION (pron.: lak-ta'y-shun). Suckling period of supplying human milk.

LACTEAL. Small lymphatic which carries fat from the villus of the intestine.

LANUGO (pron.: lan-yo'o-go). Downy hair found on new-born babes.

LARVA (pron.: la'rv-a). Stage of development; e.g., caterpillar.

LARYNGOSCOPE (pron.: la'r-ing-skoap). Instrument for viewi vocal cords.

LARYNX (pron.: la'r-inks). Voice-bo

LATISSIMUS DORSI (pron.: latt-i's im-mus do'r-see). Muscle of ar

LECITHIN (pron.: le'ss-y-thin). fatty substance essential to the ce

LEVATOR ANI (pron.: le'vv-at-a'nee). Muscle which forms t floor of the pelvic basin.

LIPASE (pron.: li'p-pace). A fa splitting enzyme.

LUMBAR REGION. The loins.

LUTEIN CELLS (pron.: lo'o-teen Yellow cells in the ovary whi form a special internal secretio

LYMPH. The fluid round the tiss cells.

LYMPHOCYTES (pron.: li'mm-f sites). White blood cells—formi twenty-five per cent of the tot

LYSINE. An essential amino-acid.

M

MALLEUS (pron.: m'ally-us). A bo of the middle ear.

MAMMARY (GLANDS). The breasts.

MANDIBLE (pron.: ma'nn-dibb-e Lower jawbone.

MANUBRIUM STERNI (pron.: man o'ob-ry-um). Part of the sternu or breast-bone.

MASSETER. Muscle which closes t jaws.

MEDULLA. The innermost part, core of an organ; e.g., suprarer gland.

MEDULLA OBLONGATA. Small porti of brain at top end of spinal co where the nerve "centres" a found.

MEMBRANA TECTORIA (pron.: te t'or-y-a). Roof membrane—pa of inner ear.

MEMBRANA TYMPANI (pron.: ti' pan-i). Ear-drum.

MENINGES (pron.: menn-in-jee Wrappings of brain and spi cord.

MEROZOITES (pron.: mee-ro-z'o-ite Small invading stage in the blo of the malarial parasite.

MESENTERY (pron.: m'ess-en-terr Sheet by which gut is slung on the back of the belly.

METABOLISM (pron.: met-a'b-bolism The total chemical changes of t body.

METACARPAL (BONES) (pron.: mett-a-ka'rr-pal). Bones of the hand.
METATARSUS (pron.: met-t'ar-sus).
MIDRIFF. *See* Diaphragm.
MITOCHONDRIA (pron.: mye-to-ko' nn-dry-a). Small rod-shaped bodies in cell cytoplasm.
MITRAL (VALVE). Heart valve between left auricle and ventricle.
MONOCYTES (pron.: mo'an-o-sites). White cells of blood—forming one to two per cent of total.
MUCIN (pron.: mu'k-in). Mucous substance.
MUSCULARIS MUCOSÆ (pron.: mus-ku-la'ris mu-ko'-zy). Small layer of muscle beneath mucous membrane of gut.

N

NEANDERTHALENSIS (pron.: na'y-ann-der-tal-e'nnsis). Of Neanderthal—name of place in Belgium where first remains of this type of early man were discovered.
NEPHRON (pron.: ne'ff-ron). The unit consisting of glomerulus and tubule of the kidney.
NEUROLEMMA (pron.: new-roal-e'mma). Sheath of axon of nerve cell.
NEURONE (pron.: new-ro'an). Nerve cell.
NEUTROPHILE (pron.: new-tro-fi'le). Staining faintly with acid or basic dyes, e.g., polymorphonuclear cells of blood.
NODES OF RANVIER. Gaps in medullary sheath of axon.
NUCLEOPLASM (pron.: ne'wk-ly-o-plasm). Protoplasm of nucleus.
NUCLEUS (pron.: ne'wk-ly-us). Vital, central part of a cell.

O

ŒDEMA (pron.: ee-de'em-a). Excess of lymph fluid in the tissues, causing swelling.
ŒSOPHAGUS (pron.: ee-s'offagus). The gullet.
ŒSTRIN (pron.: ee's-trin). Hormone from the ovary.
ŒSTRUS (pron.: e'es-trus). The state of "rutting" in animals.
OLFACTORY EPITHELIUM (pron.: ol-fa'k-tory epp-y-the'el-y-um). Lining of the nose.
OMENTUM. Apron of fat in the abdomen.
OPSONIN (pron.: o'p-so-nin). Substance which enables white blood cells to destroy bacteria.
OPTIC THALAMUS (pron.: o'p-tik th'al-a-mus). The grey mass in the middle of the brain.
ORBICULARIS OCULI (pron.: orr-b'ik-u-laris). Muscle surrounding the eyes—acts in blinking.
ORGAN OF CORTI. The essential organ of hearing in the inner ear.
OSSIFICATION (pron.: o's-sify-kay-shun). Bone formation.
OSTEOBLAST (pron.: o'ss-tyo-blast). Bone-forming cell.
OSTEOCLAST (pron.: o'ss-tyo-klast). Bone-destroying cell.
OTOLITH (ORGANS). Stony particle which stimulates sensitive hair cells as in saccule of the ear.
OVARIAN FOLLICLE (pron.: f'oll-ikle). Small blister of fluid on the ovary.
OVARY (pron.: o'-vary). Female sex organ.
OVUM (pron.: o'-vum). The egg cell which is shed from the follicle in the ovary.

P

PANCREAS (pron.: pa'n-kry-as). Gland which forms digestive juices and insulin.
PARATHORMONE (pron.: para-tho'r-moan). Hormone of the parathyroid gland.
PARATHYROID GLAND (pron.: para-thi'-roid). Glands lying behind the thyroid.
PARIETAL BONES (pron.: par-e'e-et-tal). Bones of skull cap.
PAROTID (pron.: par-o'tid). Salivary gland in cheek.
PATELLA (pron.: pat-t'ell-a). Knee-cap.
PECTORAL (MUSCLES) (pron.: pe'k-tor-al). Muscles of chest.
PENIS (pron.: pe'e-nis). Male sex organ.
PEPSIN (pron.: pe'p-sin). Digestive enzyme of stomach, splitting proteins.
PERICARDIUM. Fibrous sheath round the heart.
PERIOSTEUM (pron.: per-ry-o'ss-ty-um). Fibrous sheath round bone.
PERISTALSIS. Movement of gut.
PERITONEUM (pron.: perry-ton-e'e-um). Lining membrane of abdominal cavity.

PETRI DISH (pron.: pe'tt-ry). A dish in which bacteria are grown.

PHAGOCYTES (pron.: fa'gg-o-sites). White blood cells which devour bacteria.

PHALANGES (pron.: fal-a'n-jees). Small bones of the fingers and toes.

PHARYNX (pron.: fa'r-inks). Back of throat.

PHRENIC (NERVES) (pron.: fre'-nik). Nerves to the diaphragm.

PILTDOWN MAN. Earliest known man in England.

PINEAL (pron.: pi'n-ee-al). Small round body at back of third ventricle of the brain.

PINNA (pron.: pi'n-na). The outer ear.

PITHECANTHROPUS ERECTUS (pron.: pith-y-ka'nn-thro-pus). Half man, half ape, found in Java.

PITUITARY GLAND (pron.: pitt-y'oo-it-tary). Gland in the middle of the skull. The most important of the endocrine glands.

PLACENTA. Afterbirth.

PLANTAR FASCIA (pron.: pl'an-tar fa'ssh-ia). Fibrous tissue in sole of foot.

PLASMA (pron.: pla'z-ma). The fluid part of blood.

PLATELETS (pron.: pla't-y-lets). Smallest found bodies in blood—essential to the process of clotting.

PLEURA (pron.: plo'or-a). Lining of chest wall and lungs.

POPLITEAL (ARTERY) (pron.: pop-li'tt-ee-al). Artery behind the knee.

PORTAL SYSTEM. Veins draining the intestines, so carrying food in the blood, to the liver.

PRECIPITIN TEST (pron.: pre-si'-py-tin). Test for detecting the similarity of a protein to that of blood.

PROGESTERONE (pron.: pro'g-ester-oan). Hormone from the yellow body of the ovary.

PROSTATE (GLAND) (pron.: pro's-tait). Gland which takes a part in sex life of man.

PROTEINS (pron.: pro'-t-eens). Complex chemical substances containing nitrogen, carbon, hydrogen and oxygen. Sometimes other elements.

PROTHROMBIN (pron.: pro-th'rom-bin). Precursor of thrombin. An essential part of the clotting process of blood.

PROTOPLASM (pron.: pr'o-to-plasm). The basis of all life.

PROTOZOA (pron.: pro-to-zo'-a). Simple unicellular animals.

PSEUDO-PODIUM (pron.: su'-do p-ady-um). Process of protoplasm.

PULMONARY (pron.: p'ul-moan-ar-y). Belonging to the lung.

PURINE. A group of chemical substances like uric acid.

PURPURA (pron.: p'ur-pur-a). Bleeding (spontaneous).

PYLORUS (pron.: pi'-lo-rus). Portion of stomach.

PYRAMIDAL TRACT. Tract of nerve cells from brain to spinal cord along which the impulses governing movement travel.

PYTALIN. Enzyme in saliva.

Q

QUADRICEPS FEMORIS (pron.: kw'o-ri-sepps fe'm-mor-is). Muscles in front of the thigh.

R

RADIAL (ARTERY). Artery of the wrist (felt as the pulse).

RADIUS. Bone of the forearm.

RECESSIVE (CHARACTERISTICS). Characteristics which do not appear. cf. Dominant.

RECTICULO-ENDOTHELIUM SYSTEM. System of cells which produce particular kinds of phagocyte, e.g., monocytes, having close relation to immunity from disease.

RECTUM (pron.: r'ek-tum). Last part of colon.

RECTUS ABDOMINIS (pron.: rek-tuss ab-do'm-min-nis). Muscle in front of belly.

REFRACTION (pron.: ref-r'ak-shon). Bending of light in varying media.

REFRACTORY PERIOD (pron.: re-fra'k-tory). Period during which tissue will not respond to another stimulus.

RENAL (ARTERIES) (pron.: re'e-nal). Arteries to the kidney.

RESPIRATORY EXCHANGE. Ratio of oxygen absorbed to carbon dioxide put out by the lungs.

RETINA (pron.: re't-in-a). Sensitive part of the eye where light is detected.

RODS. Sensitive organs in the retina.

ROUGET CELLS (pron.: ro'o-sha). Cells on the walls of capillaries.

S

SACCULE (pron.: sa'k-yool). Part of the inner ear containing otolith organs.

SACRAL REGION (pron.: sa'k-ral). Round the sacrum; lower vertebræ of the spine.

SACRUM (pron.: sa'kk-rum). Lower vertebræ between lumbar vertebræ and coccyx.

SCALA TYMPANI (pron.: ska'y-la ti'm-pan-ny). Division of inner ear.

SCALA VESTIBULE. Part of inner ear connected with vestibule.

SCAPULA. Shoulder-blade.

SCLERA (pron.: sle'era). Thick white coat of the eyeball.

SCROTUM. Bag, holding the testicles.

SEBACEOUS GLANDS (pron.: seb-ba'y-sy-us). Glands which secrete sebum. In the ear they secrete the wax.

SECRETIN (pron.: se-kre'e-tin). Internal secretion of the duodenum which stimulates the pancreas to secrete its digestive juices.

SEGMENTATION. A movement of the bowel, churning up food mass.

SEMICIRCULAR CANALS. Part of the inner ear devoted to position sense. Three canals detect movement in the three planes.

SERUM (pron.: se'er-um). Blood plasma minus fibrin.

SIGMOID COLON (pron.: si'g-moyd). Last coil of colon.

SINO-AURICULAR (NODE) (pron.: si'ne-o ori'k-u-lar). Pace-maker of the heart. Where beat starts.

SINUSOID (pron.: si'ne-oo-soid). Space in bone marrow and spleen where blood cells lie.

SOL. Colloid in fluid solution.

SOLAR PLEXUS (pron.: so'al-ar ple'k-sus). Ganglia of sympathetic cells in the belly.

SOMATIC (pron.: som-a't-ik). Bodily.

SPECIFIC GRAVITY. Density in comparison with water.

SPERMATOZOA (SPERM) (pron.: sper-mato-z'o-a). Male sex cells.

SPIRILLÆ (pron.: spi-r'illy). Coiled microscopic organisms.

SPIROCHÆTES (pron.: spi-ro-ke'ets). Finely coiled microscopic organisms like spirillæ with slight differences.

SPLANCHNIC (NERVE) (pron.: spla'nk-nik). Branch of the sympathetic link to the viscera.

SPORE (pron.: sp'oar). A sexual reproducing body.

SPUTUM (pron.: spe'w-tum). Spit or phlegm.

STAPES (pron.: stay-pe'es). Small bone of middle ear.

STAPHYLOCOCCI (pron.: staf-fyl-o-k'ok-y). Cocci in groups.

STERCOBOLIN (pron.: ster-k'ob-olin). Pigment which colours fæces.

STERNO-MASTOID (MUSCLES) (pron.: st'er-no ma'ss-toyd). Muscles each side of neck.

STERNUM. Breast-bone.

STRATA. Layers (of rock usually).

STRATUM CORNEUM (pron.: str'a-tum k'or-ny-um). Horny layer of skin.

STRATUM GRANULOSUM (pron.: gra'n-u-lo'-sum). Granular layer of epidermis.

STRATUM LUCIDUM (pron.: lo'o-si-dum). Clear celled layer of epidermis.

STREPTOCOCCI (pron.: str'epp-to-kok-si). Cocci in chains.

SUBCLAVIAN (ARTERY) (pron.: sub-kla'yv-y-an). Artery running from aorta to axillary artery.

SUBLINGUAL (GLAND). Salivary gland beneath the tongue.

SUBMAXILLARY (subm'ak-sill-ary). Salivary gland beneath lower jaw.

SUPERIOR MESENTERIC (ARTERY) (pron.: mess-e'n-terik). Artery supplying most of the intestines.

SUPERIOR VENA CAVA (pron.: ve'ena ka'yv-a). Main vein from head and neck leading into heart.

SUPRARENAL GLANDS (pron.: soop-ra-re'en-al). Glands on top of the kidney which secrete adrenalin.

SYMPATHIN. Substance liberated at ends of sympathetic nerves.

SYNAPSES (pron.: sin-a'p-sees). The function of two hormones.

SYNOVIAL MEMBRANE (pron.: si-no'-vy-al). Layer of fibrous tissue round a joint.

SYNTHESIS. Building up.

SYSTOLE (pron.: si'st-oly). Contraction of the heart.

T

TARSAL (GLANDS). Glands in eyelids.

TARSUS. The small bones of the foot as a whole.

TASTE-BUDS. Cells, shaped like buds, in the tongue.

TEMPORAL BONES. Bones forming the "temple" of the skull.

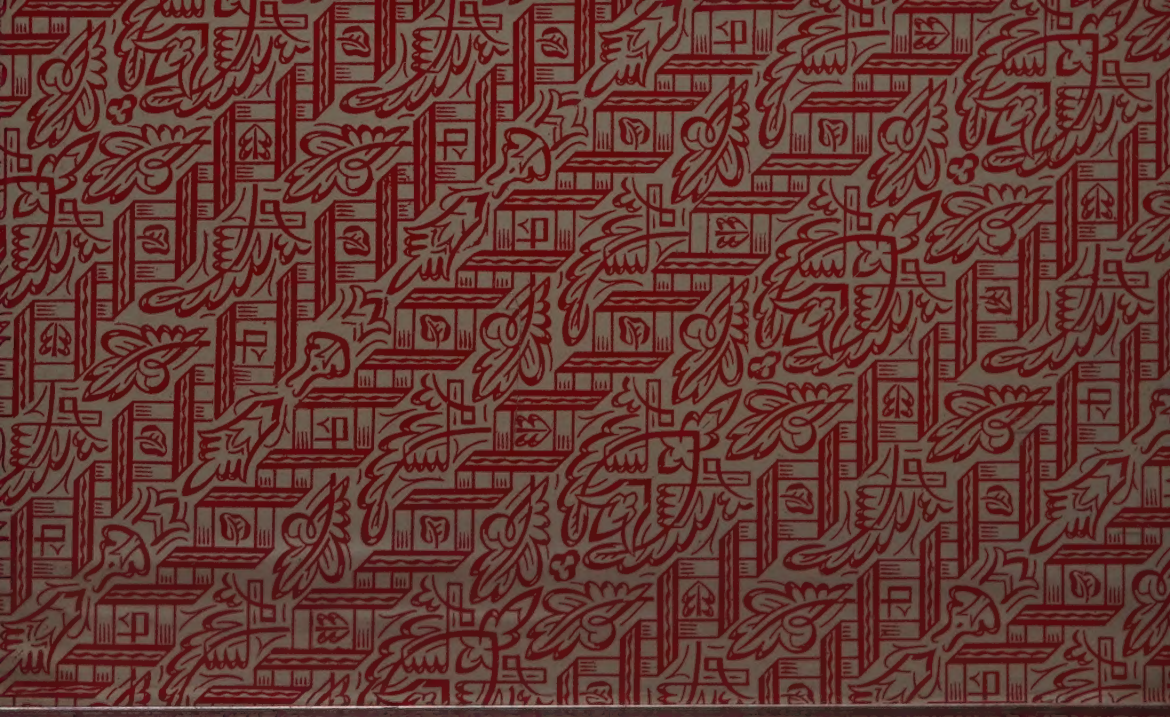
TENDO ACHILLIS (pron.: te'n-do ak-y'll-iss). Tendon of gastrocnemius at back of heel.
TESTES (pron.: te'st-tees). Male gonads.
TESTOSTERONE (pron.: te'st-oster-oan). Internal secretion of testes.
TETANY (pron.: tet-any). Form of spasm.
THORACIC REGION (pron.: thor-ass-ik). Chest region.
THROMBIN (pron.: thr'om-bin). Part of the series of substances essential to clotting of blood.
THROMBOKINASE (pron.: thro'm-bokin-aze). Another essential to blood clotting.
THROMBOSIS (pron.: throm-b'o-sis). Clotting of blood in the body.
THROMBUS (pron.: thr'om-bus). A clot in a living vessel.
THYMUS (pron.: thi'-mus). A gland in the neck below the thyroid.
THYROID (pron.: thi'-roid). A gland in the neck: secretes thyroxine.
THYROXINE (pron.: thi-r'ok-sin). The hormone of the thyroid gland.
TIBIA (pron.: t'ibby-a). Main bone of leg.
TOXIN (pron.: t'ok-sin). A poison secreted by bacteria.
TRACHEA (pron.: trak-e'e-a). Windpipe.
TRANSVERSE COLON (pron.: ko'al-un). Part of colon which passes from right to left.
TRAPEZIUS (pron.: trap-e'ez-y-us). A muscle of neck and back.
TROCHANTER (pron.: trok'-an-ter). Process of bone at upper end of femur.
TRICUSPID (pron.: tri-ku'ss-pid). Valve of heart, leading from right auricle to ventricle.
TRYPSIN. Digestive ferment of pancreas. Acts on protein.
TUBERCULE (Darwin's) (pron.: tu'b-er-kel). A small knob on the ear representing vestigial point.
TURBINATE (BONES) (pron.: tu'r-bin-ait). Coiled bones in the nose.

U

ULNA (pron.: o'ol-na). Bone of forearm—on little finger side.
UMBILICAL (CORD) (pron.: um-bil-y'-kal). Cord connecting fœtus and placenta.
URÆMIA (pron.: yoo-re'e-my-a). Condition of poisoning from kidney failure.
UREA (pron.: yoo-re'e-a). Waste product formed from unused amino acids by the liver.
URETER (pron.: yoor-e'eter). Tube from kidney to bladder.
URETHRA (pron.: yoo-ree-thra). Tube from bladder to outside.
UROCHROME (pron.: yo'o-ro-kroam). The pigment colouring the urine.
UTERUS (pron.: yo'o-ter-us). Womb.
UTRICLE (pron.: yo'o-trik-el). Part of inner ear.

V

VACCINE (pron.: va'k-seen). A substance which is injected to cause the formation of antibodies, so that immunity is established.
VAGINA (pron.: va-ji'na). Canal leading from womb to surface of the body.
VAGUS (NERVE) (pron.: v'ay-gus). The tenth cranial nerve—supplies most of the viscera.
VASOMOTOR (CENTRE) (pron.: v'ay-zo). Nervous centre in the medulla oblongata.
VAS DEFERENS (pron.: v'ass d'ef-er-ens). Duct carrying sperm from testes to urethra.
VERTEBRATES (pron.: v'er-ty-braits). Backboned animals.
VESTIGIAL STRUCTURES (pron.: ves-t'ijy-al). Structures—useless now but indicative of past development, e.g., appendix.
VIBRIO (pron.: vi'-bry-o). A curled microscopic organism.
VILLUS. Projection of small intestine mucosa which absorbs food.
VISCERA (pron.: vi's-ser-a). Organs such as lung, kidneys, etc.
VISUAL PURPLE. Pigment in the retina which is acted on by light.
VITREOUS HUMOUR (pron.: vi't-ry-us). Thick fluid in posterior chamber of eye.

Z

ZYGOMATIC PROCESS. Process of temporal bone leaning forward to the cheek.
ZYGOMATICUS. Muscle of face leaning from zygomatic process to lip.
ZYGOTE. The fertilized ovum.
ZYMOGEN. Precursor of secretion contained inside the cell.